BTO Transactive Portfolio at ORNL

Presented by

Teja Kuruganti, Ph.D

Oak Ridge National Laboratory

April 17th 2019

ORNL is managed by UT-Battelle, LLC for the US Department of Energy

Acknowledgements – ORNL Team

- Michael Starke
- Heather Buckberry
- Piljae Im
- Helia Zandi
- Jin Dong
- Jeff Munk
- Chris Winstead
- James Nutaro
- Brian Fricke
- Mahabir Bhandari
- Pooran Joshi
- Madhu Chinthavali
- Jian Sun
- Robert Smith
- Mohammed Olama
- Alex Melin
- Borui Cui
- Supriya Chinthavali
- Stephen Killough
- Sonny Xue
- Kyle Gluesenkamp
- Vishal Sharma
- Jaewon Joe
- Students
- Collaborators

Opportunity Space

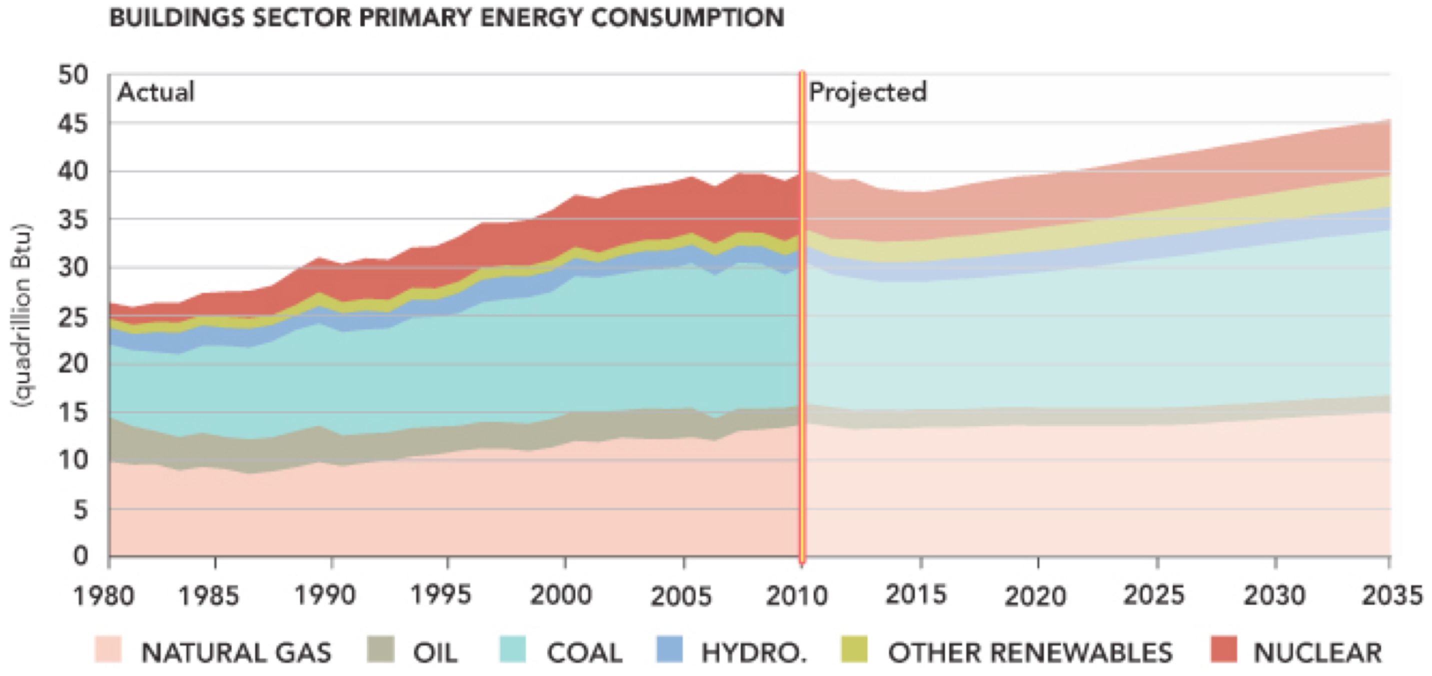
Buildings consume 74% electricity produced in the US

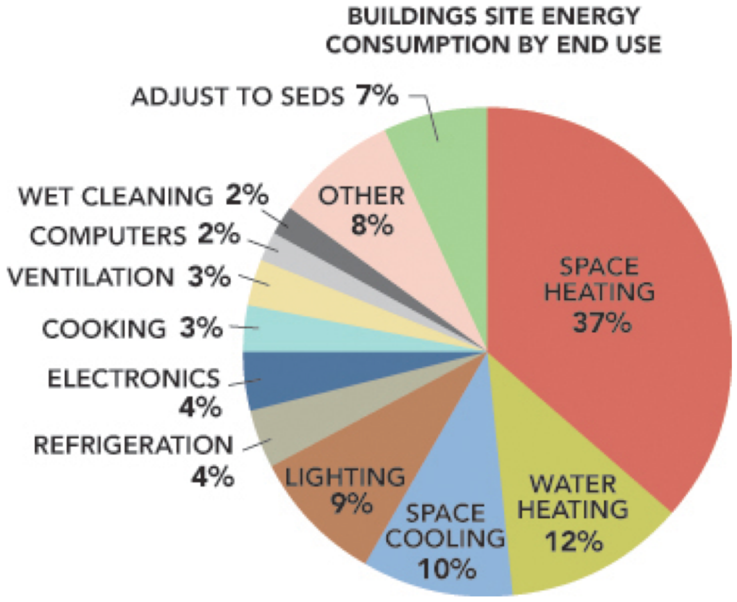
Buildings have the potential to reduce their consumption by 20%-30% (18 quads or 2,500 million tons of oil) through advanced sensors and controls

Potential nationwide value of demand dispatch could be several billion dollars yearly in reduced energy costs with 10% participation (NETL, Demand Dispatch – Intelligent Demand for a More Efficient Grid, August 2011)

One-fourth of the 713 GW of US electricity demand in 2010 could be dispatchable

90% of the commercial buildings are < 50,000 ft^2 and need aggregation



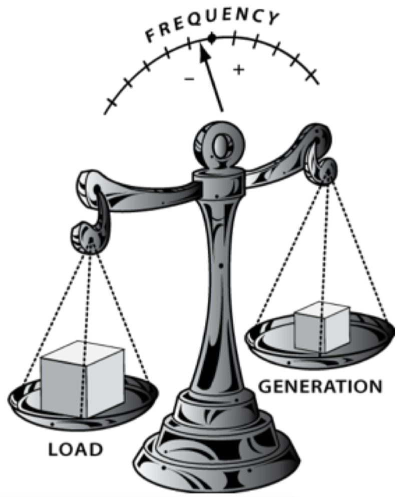


5.5 million commercial, 117 million residential, projected to be 80% of load growth through 2040

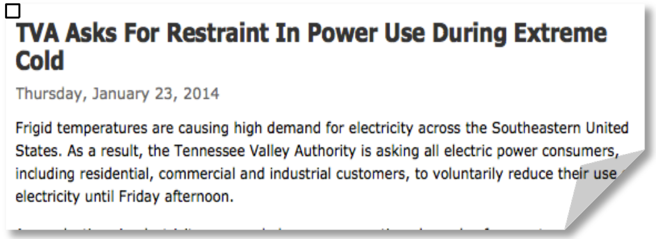
Source: 2015 Annual Energy Outlook with Projections to 2040, U.S. EIA. April 2015

It is a delicate balancing act

Load > Generation – under frequency → Load < Generation – over frequency → When you see frequency change – it is too late.



Currently: Not real-time	
	Bookkeeping to ensure that load and generation are balanced
	Measure power flows
	Control the balance in our balancing area.
Why is this important now?	
	Integration of renewables (wind and solar)
	Reduction requirements of emissions
	Cost of ancillary generation
	Increasing reliability requirements
	Increasing demand



TVA Asks For Restraint In Power Use During Extreme Cold

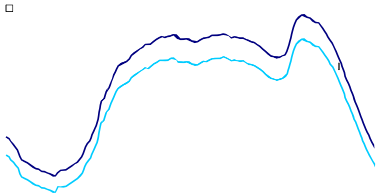
Thursday, January 23, 2014

Frigid temperatures are causing high demand for electricity across the Southeastern United States. As a result, the Tennessee Valley Authority is asking all electric power consumers, including residential, commercial and industrial customers, to voluntarily reduce their use electricity until Friday afternoon.

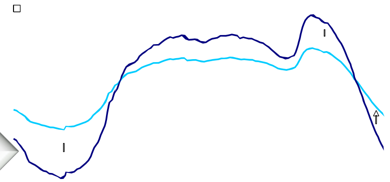
Peak	31000 – 33000 MW
Direct reduction	1000 MW
Each degree <20	400 MW

What types of responsive loads are needed

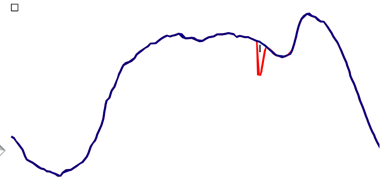
Energy efficiency: Reduce electricity consumption and usually reduce peak demand.



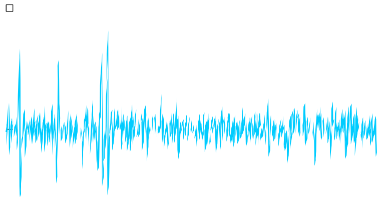
Peak shaving/shifting: Move consumption from day to night.(Price Response, Direct Load Control)



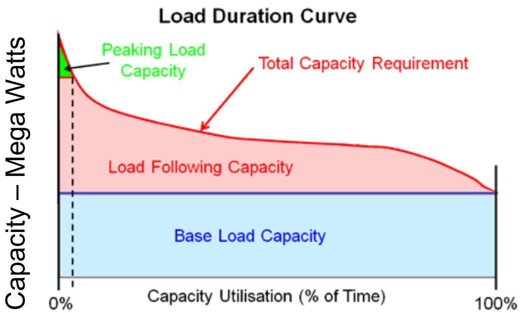
Reliability response (contingency response): Requires the fastest, shortest duration (required during power system "events") **–** engage DERs and Power Electronics



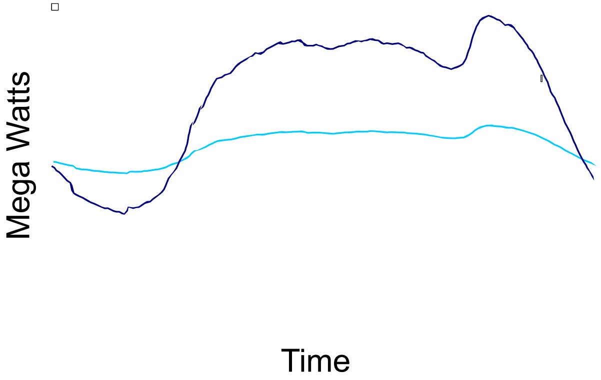
Regulation response: Continuously follows the power system's minute-to-minute commands to balance the aggregate system **– very new and could dramatically change electricity costs**



ORNL's Focus– Transactive Control



Coordinate Large Number of Building Loads



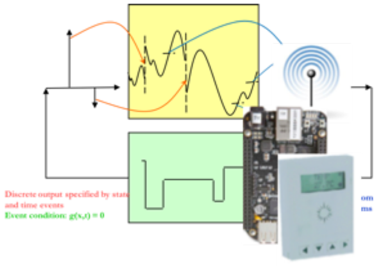
Reduce Energy Intensity and Increase Energy Efficiency

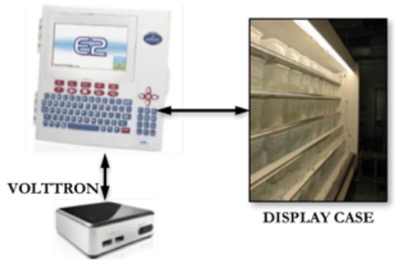
Mega Watts

Time

Increase Load Flexibility and Improve Grid Resiliency

- **Coordinate building loads - Grid response**
- **Advanced control systems – Retrofit platforms**
- **Embedded in next generation equipment**
- **Field Verification and Validation**



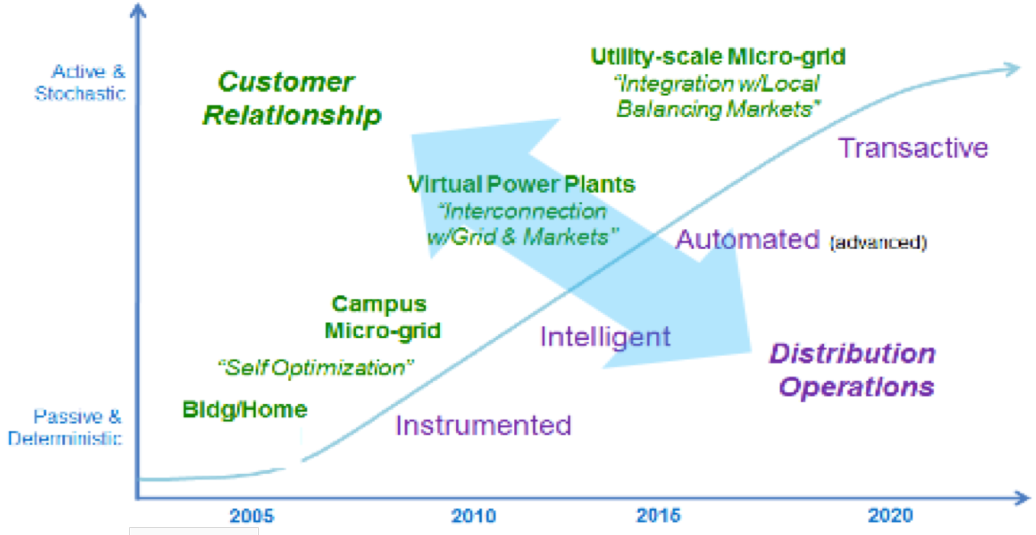


Retrofit Platforms

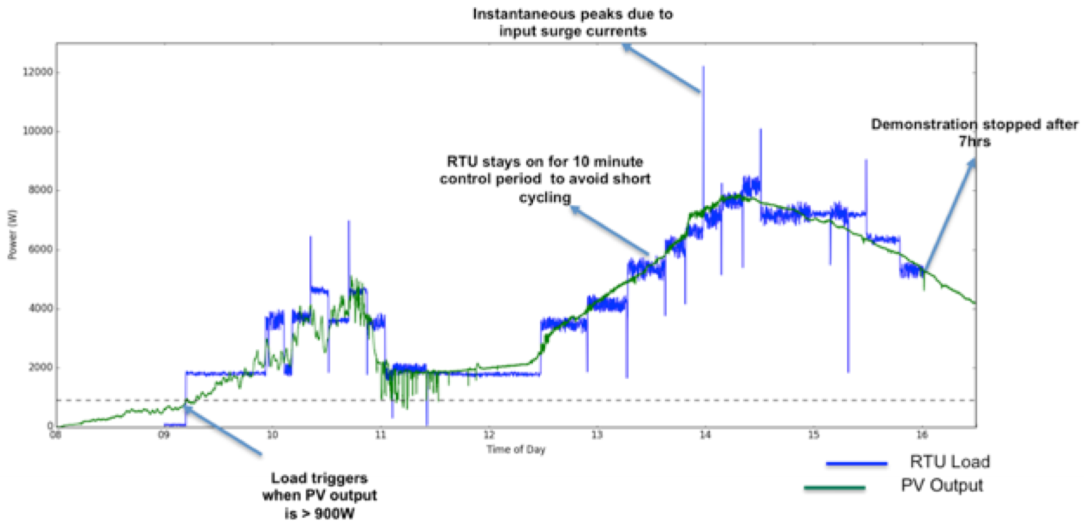
Next Generation Equipment

Value Proposition

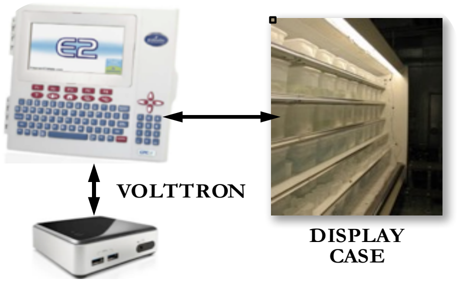
- From the Grid Perspective
  - Increase and enhance the hosting capacity renewables and improve resiliency - *"thinking beyond DR"*
    - Fast Demand Response
    - Ancillary Services
    - Load Shifting
- From the Building Perspective
  - Enable behind the meter automation technologies to **drive EE** deeper or through new means - *"thinking beyond EE"*
    - Fully automated, self learning, dynamic and responsive
    - Create a market for EE solutions
    - Seamless deployment

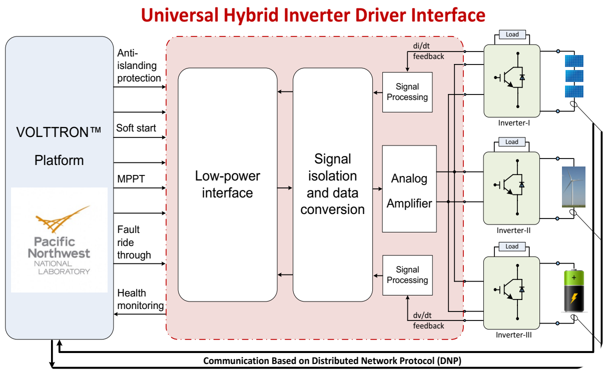


Stages of adoption of transactive operations for industry
Source: Paul De Martini, 1st International Conference and Workshop on Transactive Energy[9]



Current ORNL Projects - Snapshot





Connected Loads

Retrofit Supervisory Control Systems

AI/Machine Learning

Virtual/Thermal Storage

DER Integration

Open-source Interfaces to Inverters and Appliances

RE-responsive Load Control

Virtual Inertia

Field Evaluations

Resilient Distribution Systems

Connected Neighborhood

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Project Team

Southern Company:
Utility provider, host of developed software, API developer, historian.

Oak Ridge National Laboratory:
Transactive platform architect, optimization, data evaluator, dashboard

Alabama Power: Centralized

Rheem: Water Heater and Device API provider
Carrier: HVAC and Device API provider

MICROGRID:
Samsung: Energy Storage
PowerSecure: Power Electronics and Integration
ORNL: Microgrid Controller

Georgia Power: Decentralized

A.O.Smith: Water Heater provider
SkyCentrics: Water Heater API
Lennox: HVAC provider
Ecobee: HVAC API provider
Delta: Power Electronics System and API
LG Chem: Energy Storage Provider
eMotor Works: EV Charger

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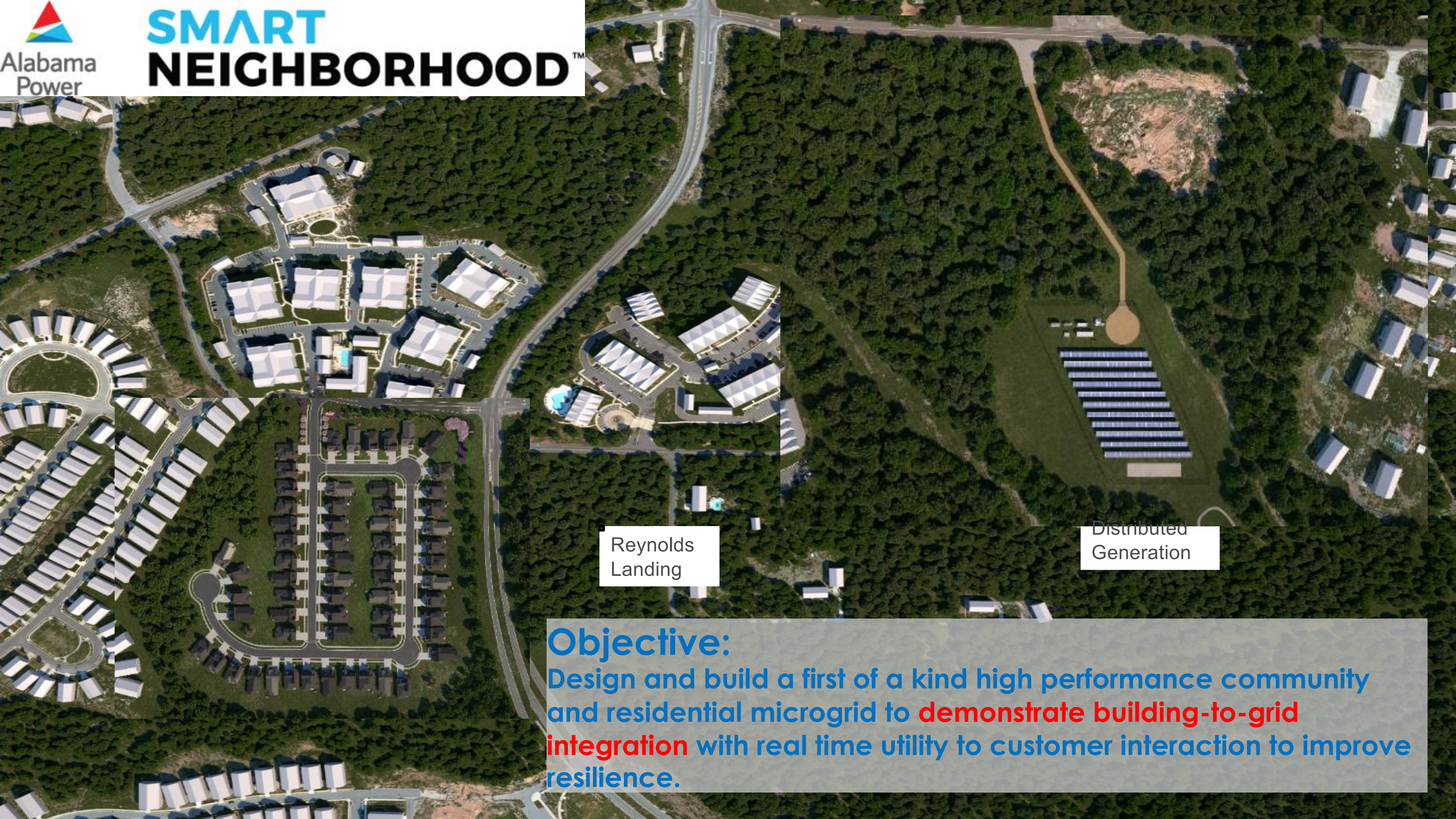
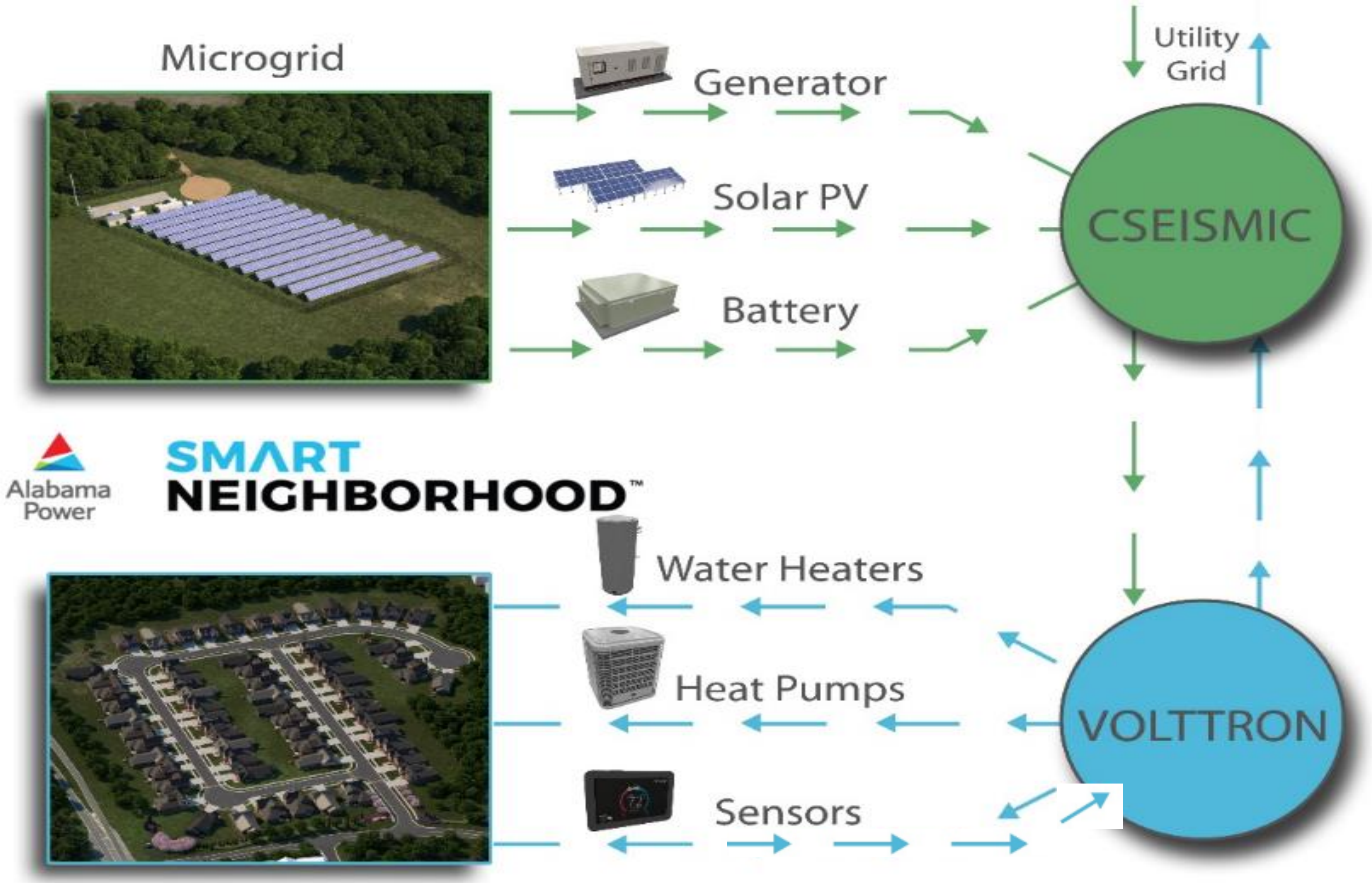
Alabama Power

SMART NEIGHBORHOOD™



Objective:

Design and build a first of a kind high performance community and residential microgrid to demonstrate building-to-grid integration with real time utility to customer interaction to improve resilience.



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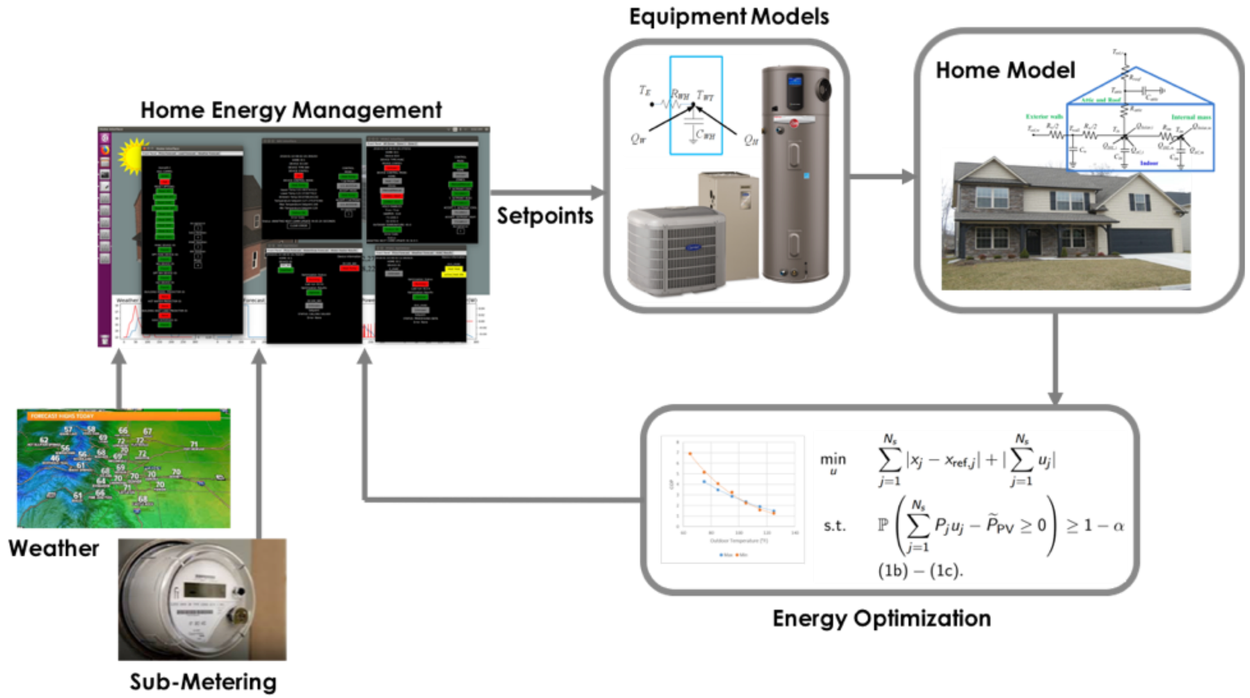
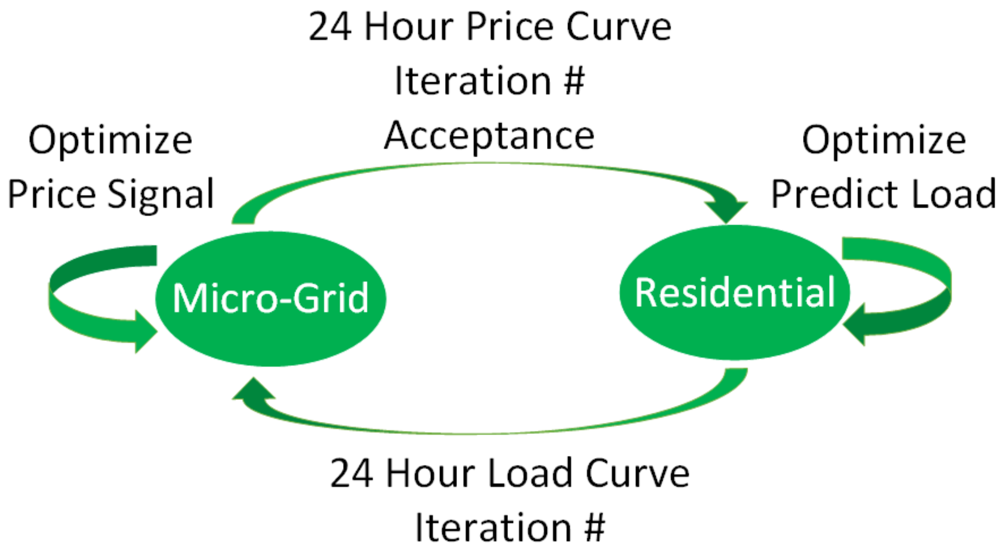
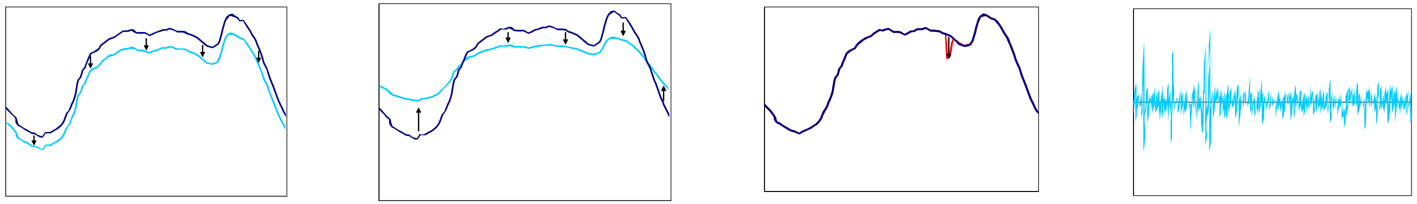
Two-levels of optimization

Residential-level Optimization



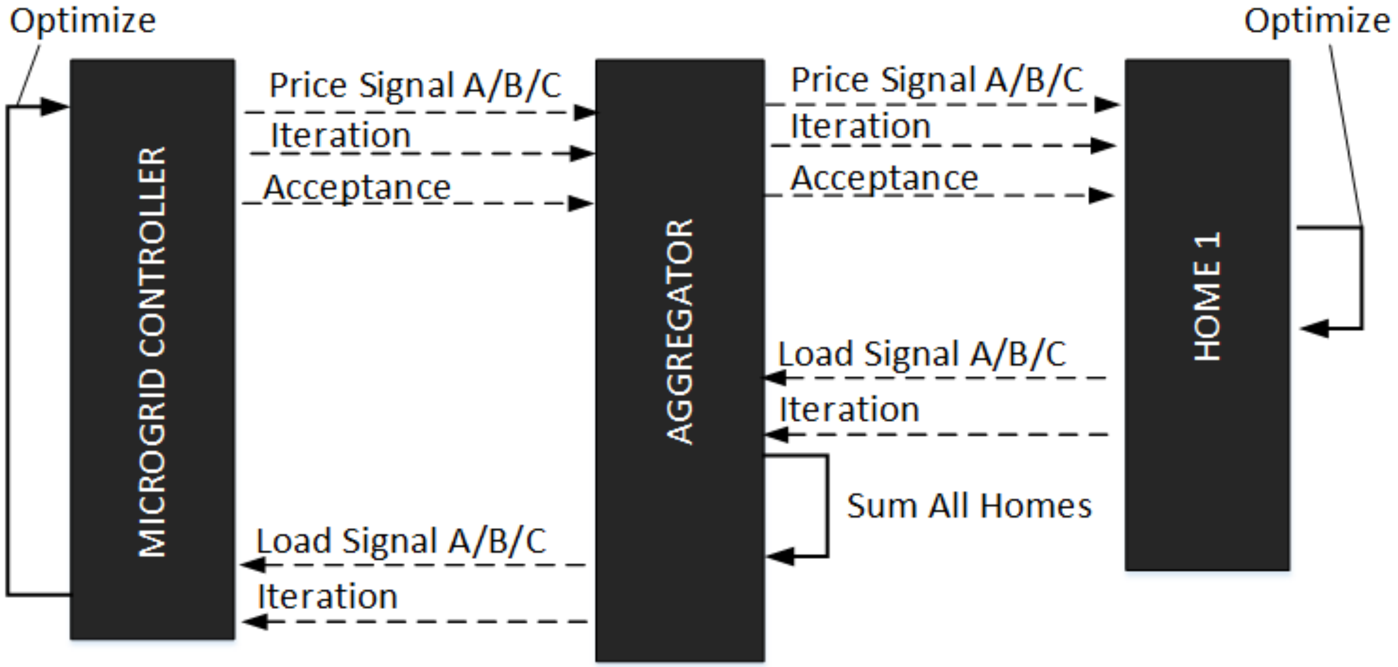
Neighborhood-level Optimization





Approach: Transactive Control (Alabama Centralized)

- Microgrid controller and VOLTTRON 'negotiate/transact' a load/price
- Microgrid controller optimizes resources and creates 24 hour pricing offer.
- VOLTTRON allocates price signals to resources (loads) which optimize and provide total load projection
- This process iterates until Microgrid controller meets minimum convergence criteria.



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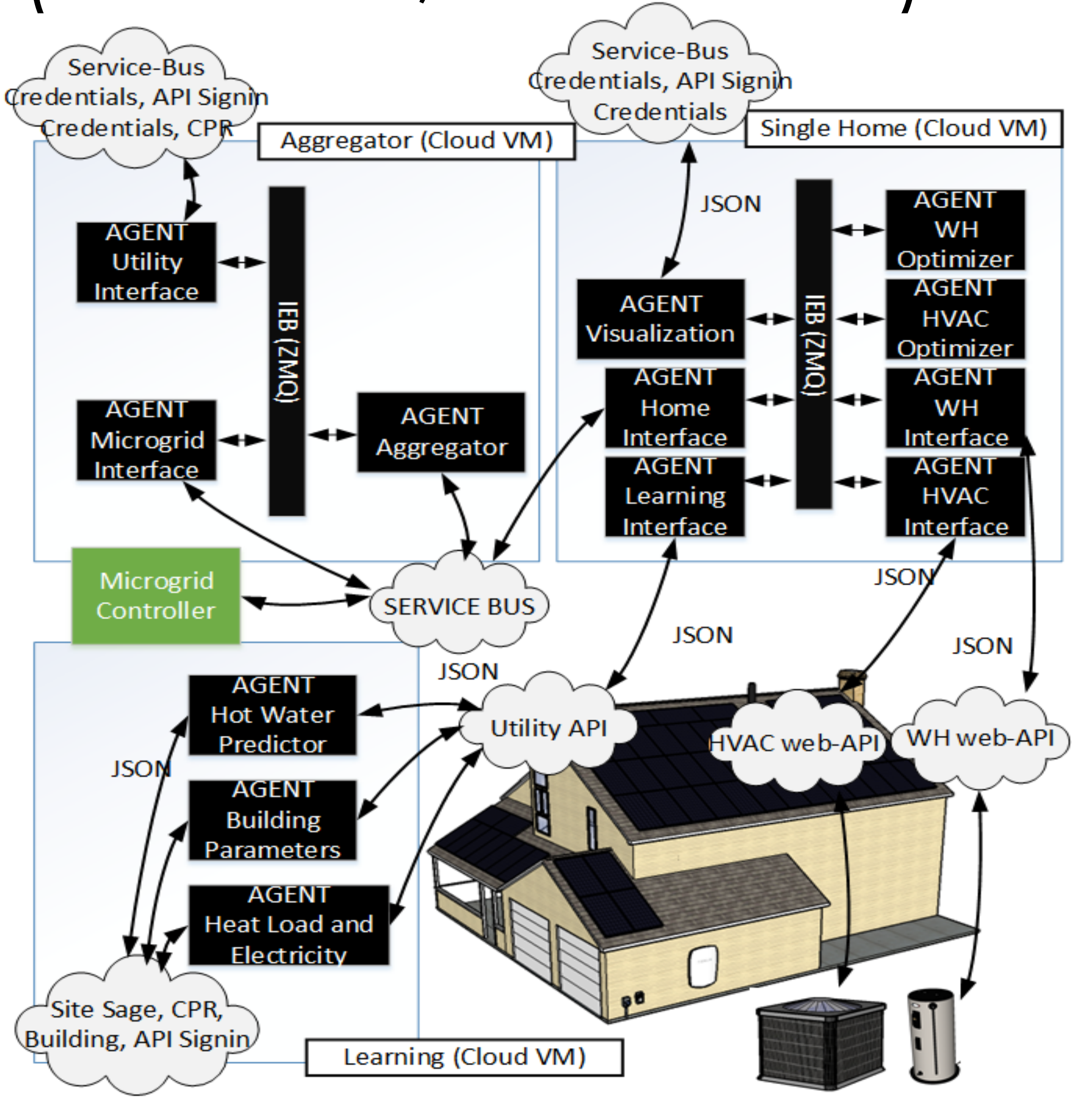
Approach – Agent Framework (Alabama, Centralized)

Agent based framework to support autonomous integration and negotiation of load resources with a microgrid controller.

Agent	Purpose
Home Interface	Data Pass through and collector of optimization and electrical consumption projections for Aggregator agent
HVAC Interface	Translates HVAC decisions and status to vendor API
Water Heater Interface	Translates Water Heater decisions and status to vendor API
HVAC Optimizer	Utilizes building specifications, forecasted weather data, building parameter data, price forecast, and HVAC status data to optimally schedule HVAC and provide expected electrical consumption.
Water Heater Optimizer	Utilizes predicted water consumption, price forecast, and Water Heater status data to optimally schedule Water Heater and provide expected electrical consumption.
SoCoInterface	Pulls data from Southern Company API which includes weather, building specifications, historical load measurements by circuit, device credentials, and historical data.
Learning	Utilizes data collected from SoCo stored data to perform predictions on hot water usage, internal heat loads, building parameters, etc.



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M. Starke, J. Munk, H. Zandi, T. Kuruganti, H. Buckberry, J. Hall, J. Leverette, "Agent-Based System for Transactive Control of Smart Residential Neighborhoods," IEEE Power and Energy General Meeting, 2019 (accepted).

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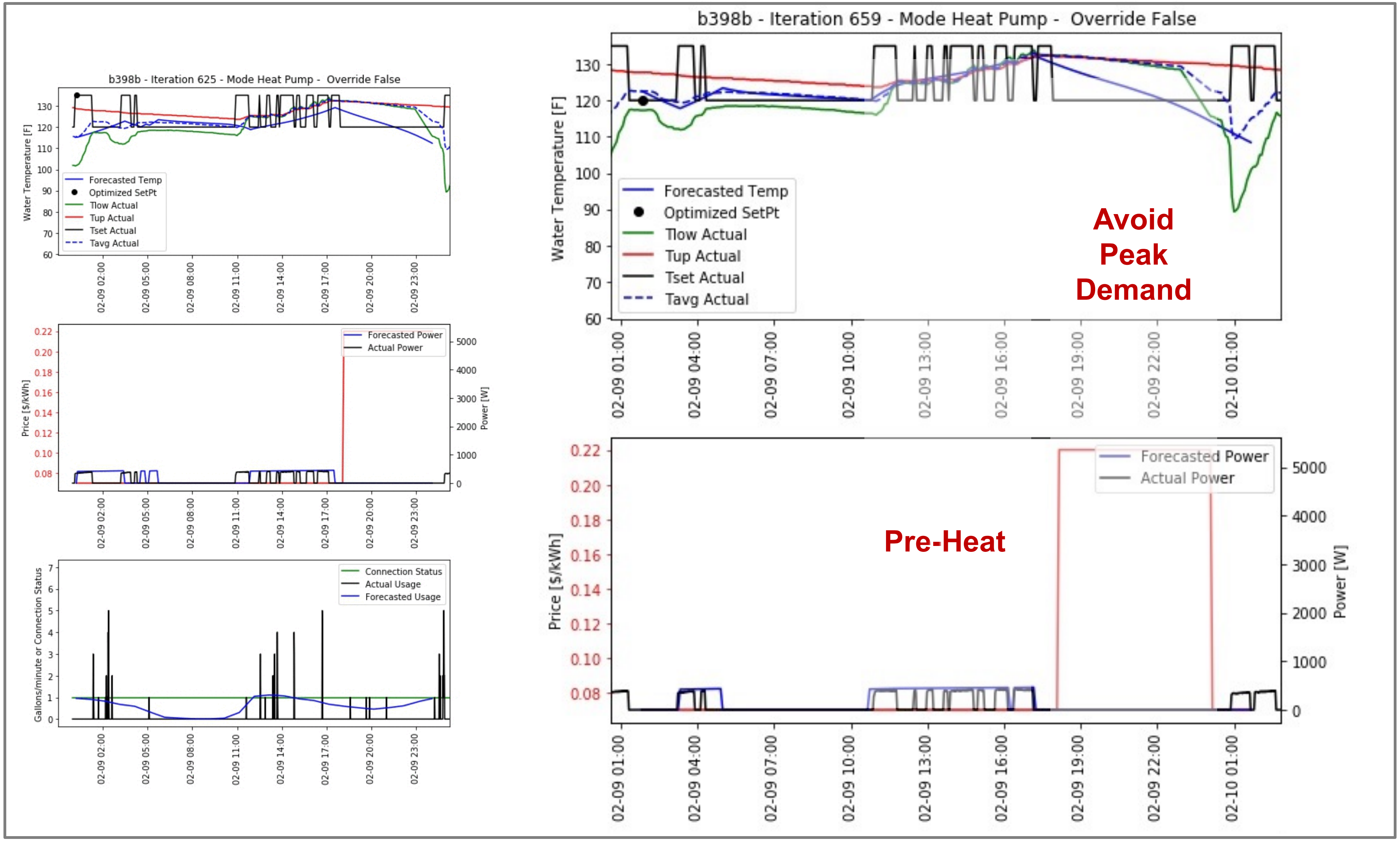
VOLTRON Devices | Data | Decisions

WATER HEATER CONTROLS



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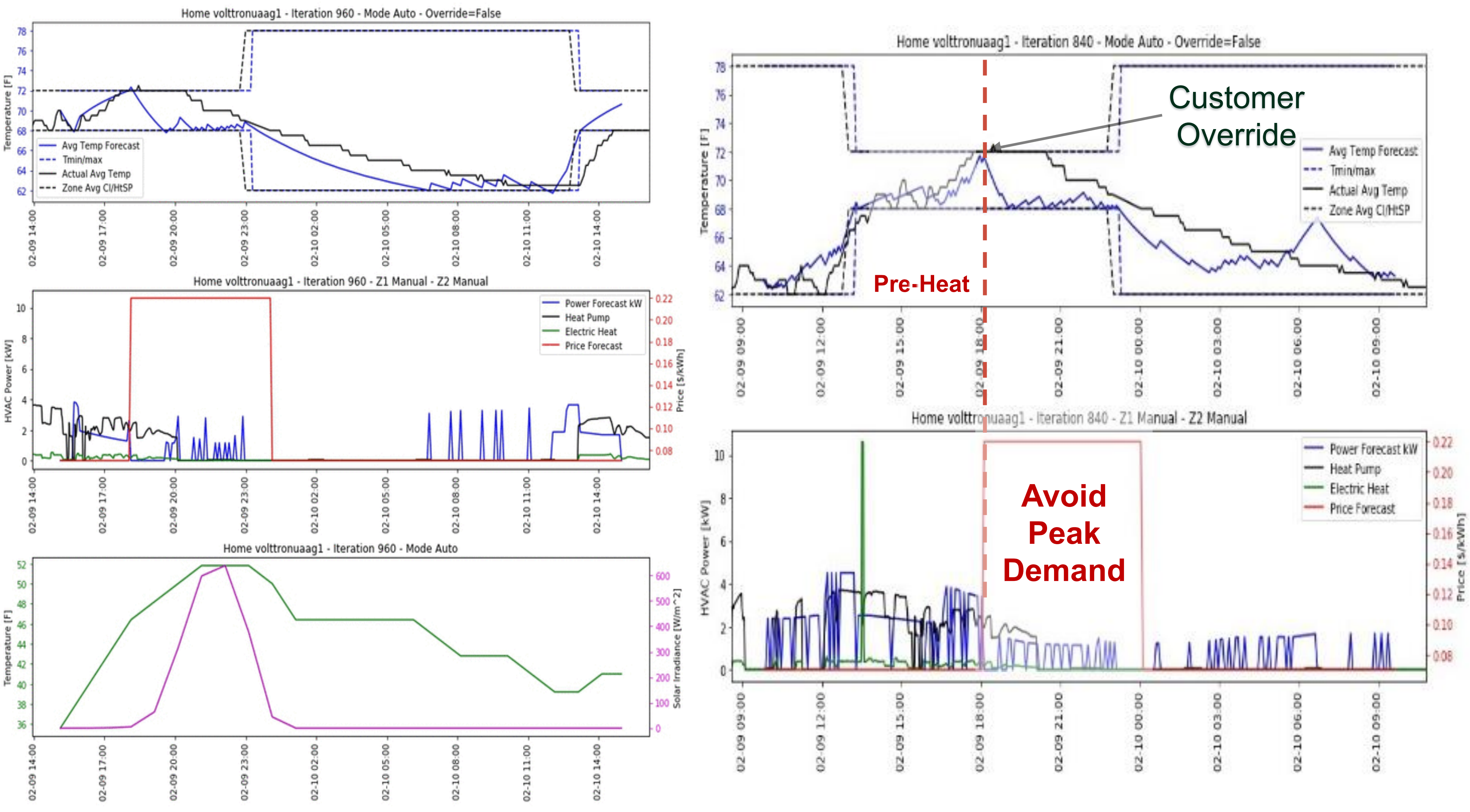
HVAC CONTROLS



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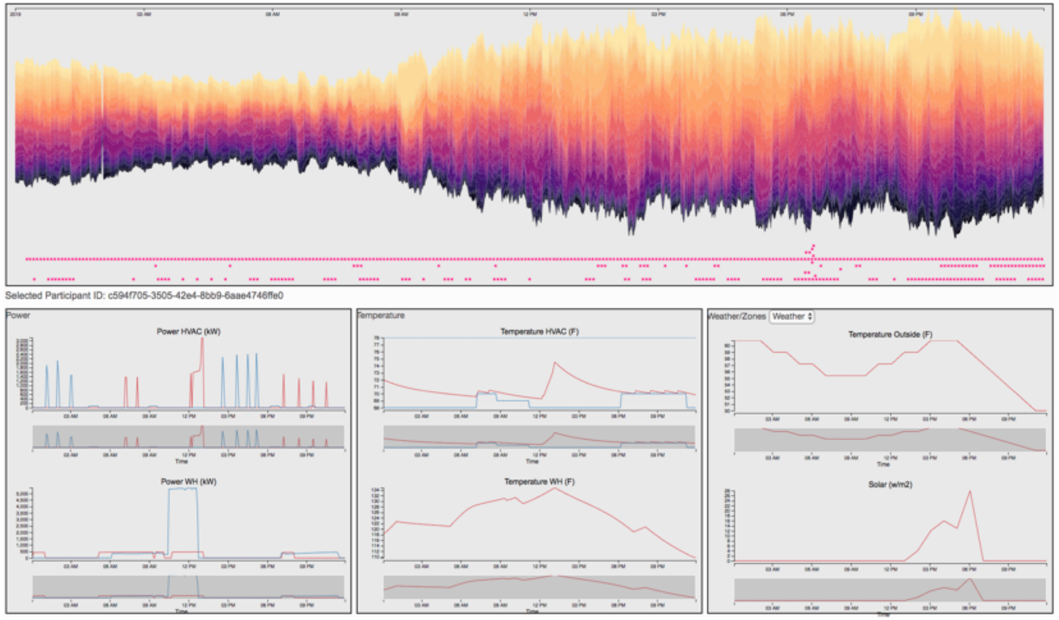
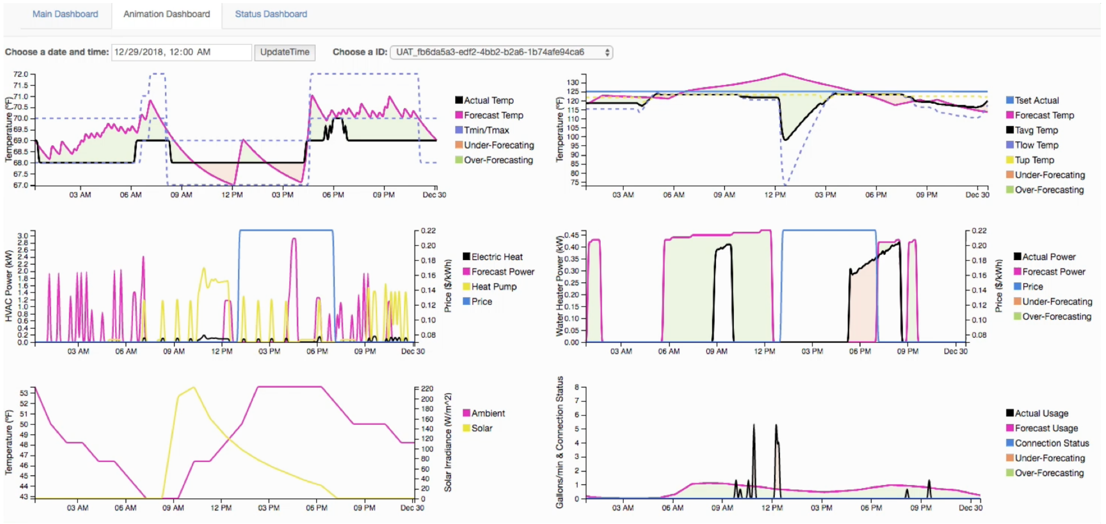
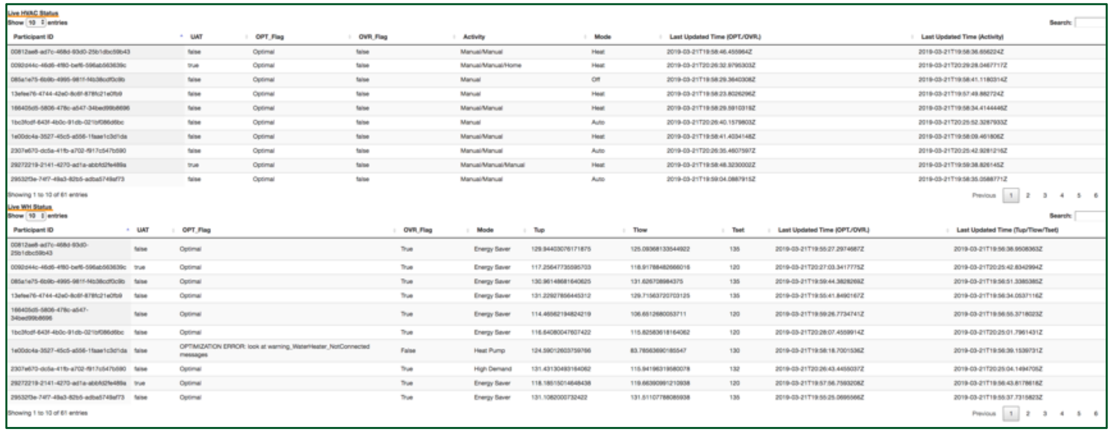
Dashboards in Development for Analysis







<u>Interactive web-based visualization Dashboards</u>

- **Live situational awareness of the neighborhood**
  - (HVAC and WH Power usage,
  - Connection status
  - Weather, Zonal level
- **WH and HVAC Optimization Animation**
  - Price Signals
  - Over-forecasting and under-forecasting
- **HVAC and WH Status:** Activity, Mode, Temperatures, Optimization and Override status

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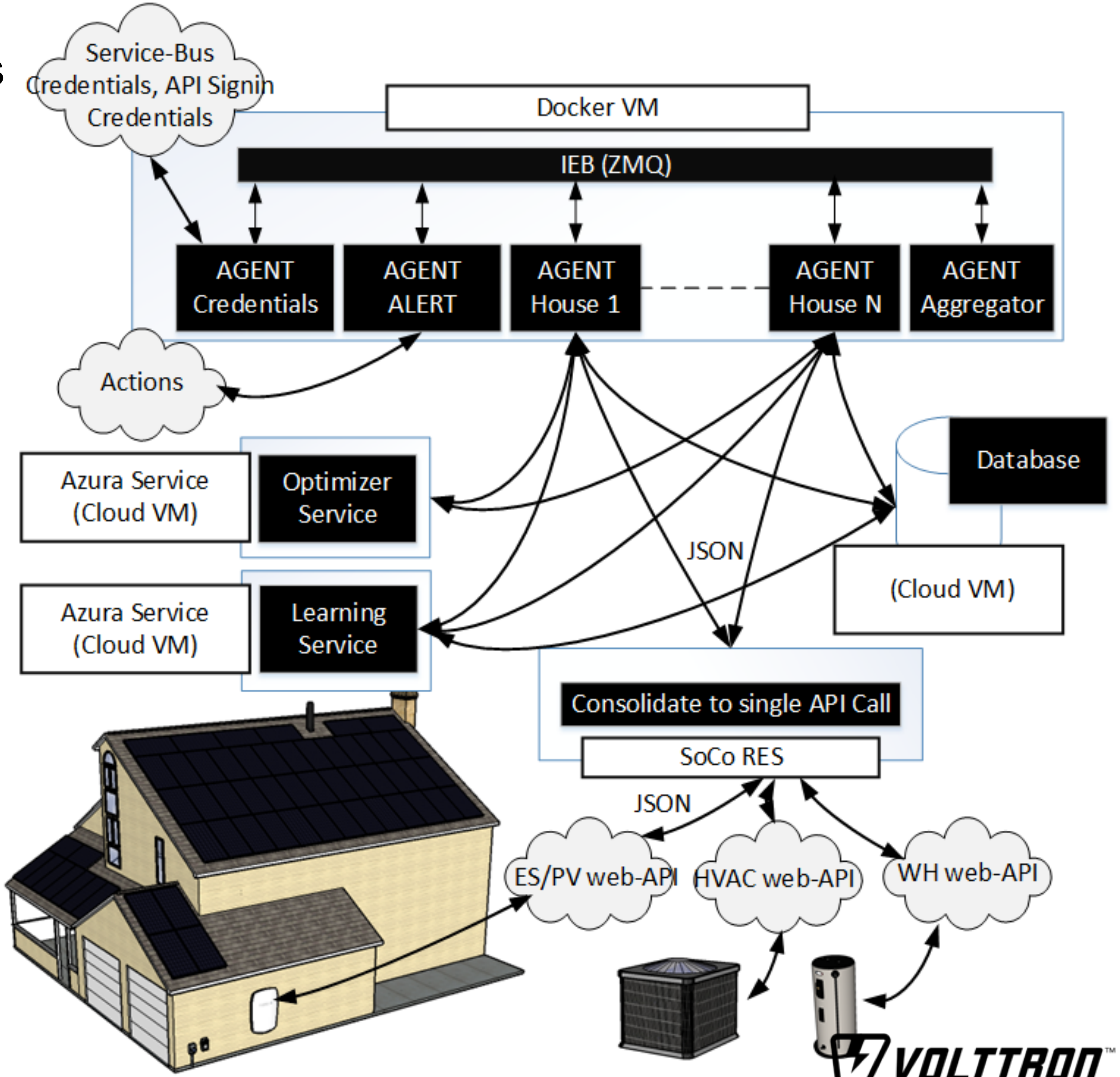
Approach – Agent Framework (Georgia, Decentralized)

Agent based framework to support autonomous integration and negotiation of load resources.

Architecture modified based on findings from Alabama.

Agent	Purpose
Home	Collects and sends device data and control setpoints to SoCo RES, calls optimization service, broadcasts and listens to Aggregator for price signal
ALERT	Receives notifications of system issues from each House and reports actions to SoCo system
Credentials	Collects necessary credentials to be used by each house management system.
Aggregator	Collects and distributes data to each home management system

Service	Purpose
Optimizer	Service spawned upon a call to optimize based on data provided. Data provided is projected device performance and load control solution.
Learning	Service spawned upon a call to develop variables needed for optimization based on historical data



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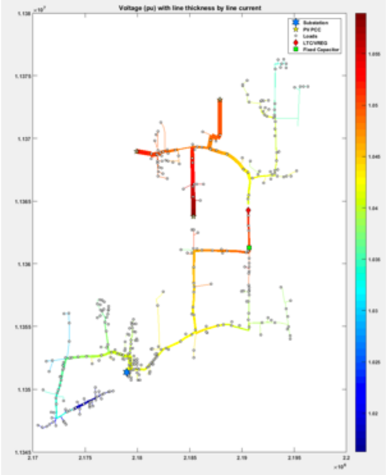
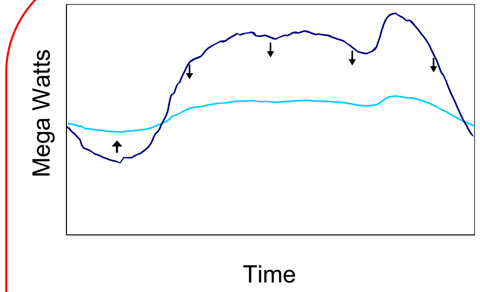
VOLTTRON™ Devices | Data | Decisions

Improve Resilience – Engaging Building Loads/DERs

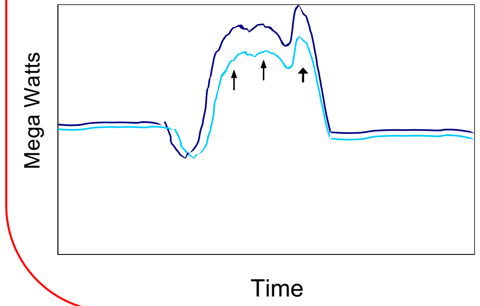


Distribution Reconfiguration

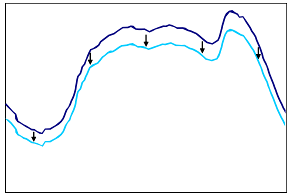
Coordinate Large Number of Building Loads



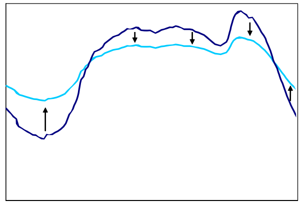
Reduce Energy Intensity and Increase Energy Efficiency



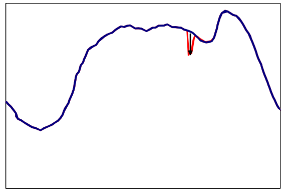
Increase Load Flexibility and Improve Grid Resiliency



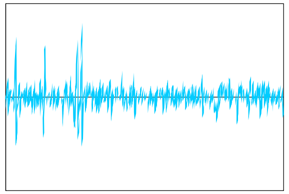
Capacity



Load Shaping



Reliability



Regulation

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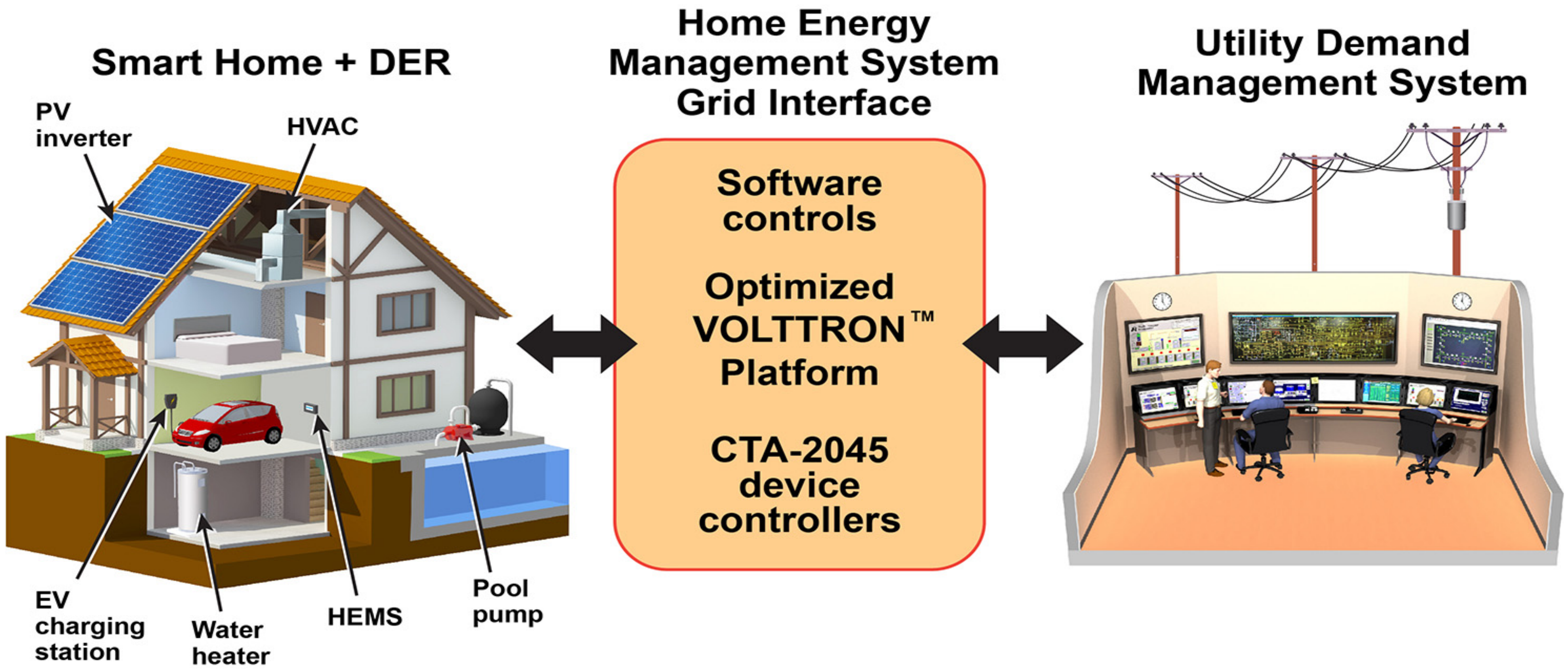
Resilient Distribution Systems

Resilient distribution systems with high penetration of distributed energy resources (DERs) that can withstand disasters and faults by intelligent reconfiguration



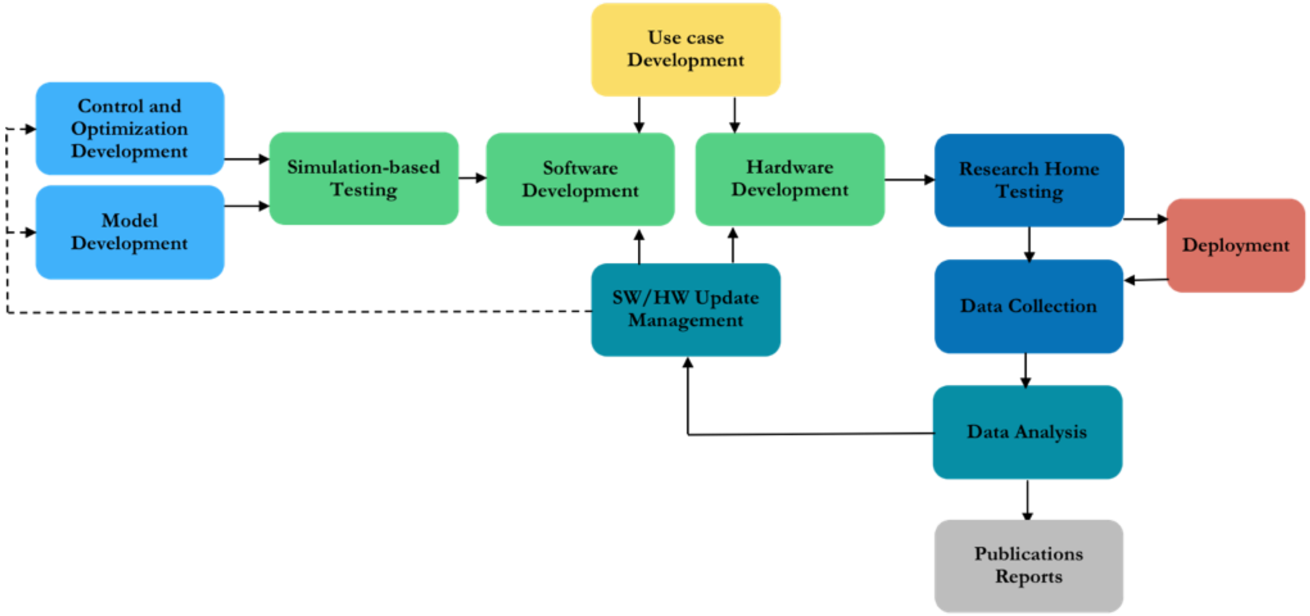
Develop end-to-end interoperable software and hardware system for engaging residential responsive loads and DERs to provide grid services

Integration of Responsive Residential Loads into Distribution Management Systems

End-to-end system for engaging residential DERs to provide grid resilience services

Project Objectives

- ✓ Develop **interoperable home energy management system** (HEMS) as an interface to distribution-level integration of Residential loads and DERs to provide distribution resiliency services
- ✓ Develop transactive control system to **co-optimize Loads performance** to satisfy grid requirements and residential needs
- ✓ Deploy and **validate the technology** in field with utility partners



Value Proposition

- ✓ Increasing number of smart residential-level assets including controllable loads, rooftop solar, and storage technologies imposing new challenges in distribution operations
- ✓ These assets can be leveraged for enabling resilient rapid reconfiguration of the distribution circuits by managing demand, voltage, and power flows
- ✓ An end-to-end solution establishing interoperability across the meter and coordinated control technology is needed to engage residential loads for grid services
- ✓ The end-to-end system performance and resilience has to be validated in field for adoption

Modeling, Simulation, Controls, Software

M&V, Software, Analytics

Hardware, Analytics, Deployment

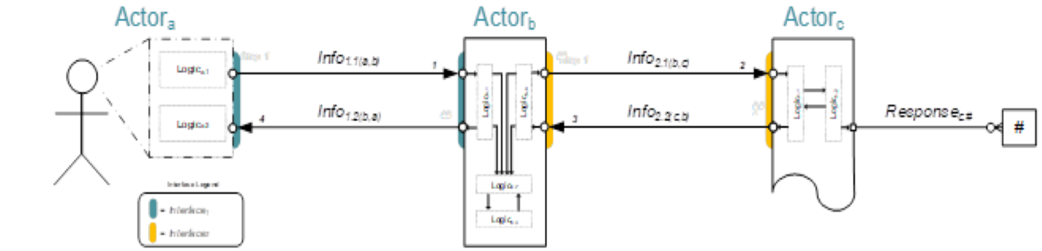
Requirement Definition, Deployment

Method of Design - Systems to Enable Behind-the-Meter Grid Services

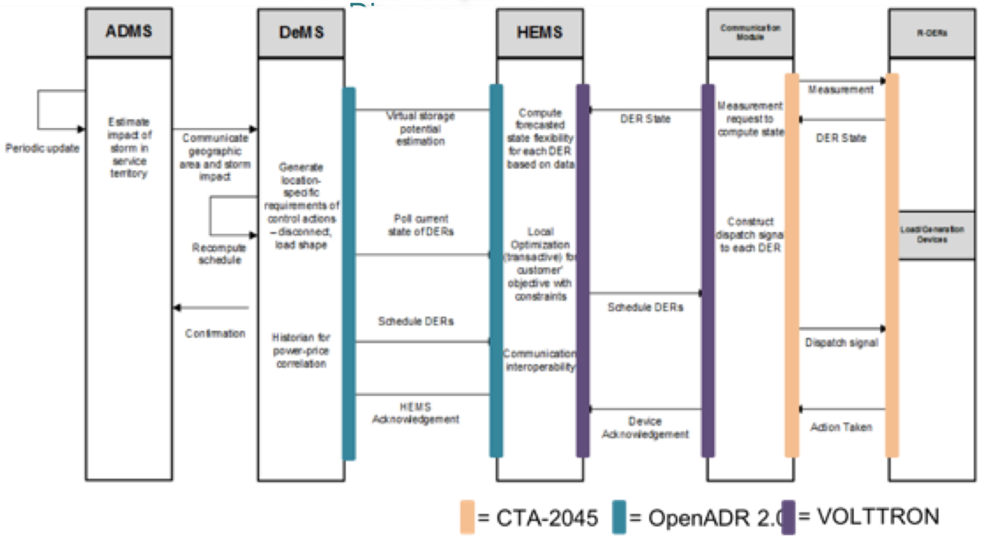
Use case and System Architecture Development

- **Design Templates**
  - Stakeholder Questionnaire
  - Use-case Narrative – 14 use cases developed
  - Actor Specifications
    - Information Exchange and Communication Interfaces
- **Graphical Representations**
  - Layered architectural diagrams (information exchange sequence)
- **Unified Documentation**
  - System Design Package
- **System Architecture**
  - End-to-end system architecture to support hierarchical control of demand side assets to provide unified response
  - Demand management system (DeMS) coordinates the communication with HEMS for transactive control using incentives to drive optimization
  - Local HEMS coordinates device response to grid service request while maintaining customer constraints
  - Interoperability and cybersecurity driven by requirement definition

Layered Architecture Diagrams



Use case Sequence Diagram



System Design Package

SYSTEM DESIGN DOCUMENTS

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Use Cases Developed

UC #1	Reduce Critical Peak Load
UC #2	Improve Disaster Preparedness through Real-time Situational Awareness and Distribution Operations Planning
UC #3	High Penetration of Renewable Energy in Distribution Systems
UC #4	Virtual networked microgrids in distribution circuits to enable resilience
UC #5	Improves Asset Utilization through Locational Pricing
UC #6	Reduce Outage and Recovery times through intelligent Cold Load Pickup
UC #7	Residential-level islanding with Assets Sensing a Grid Event
UC #8	Distribution Feeder-level Battery for Transmission Level Grid Service and Enabling Distribution Resilience
UC #9	Inverter Control to Prevent Power Generation Curtailment due to Control of Distribution-level Voltage Control Assets (e.g. capacitor banks)
UC #10	Adaptive control of DERs on a Distribution Radial Line to Stabilize Voltage Sag across a Line
UC #11	Power flow and Congestion Management
UC #12	Load Control to Support Frequency Regulation

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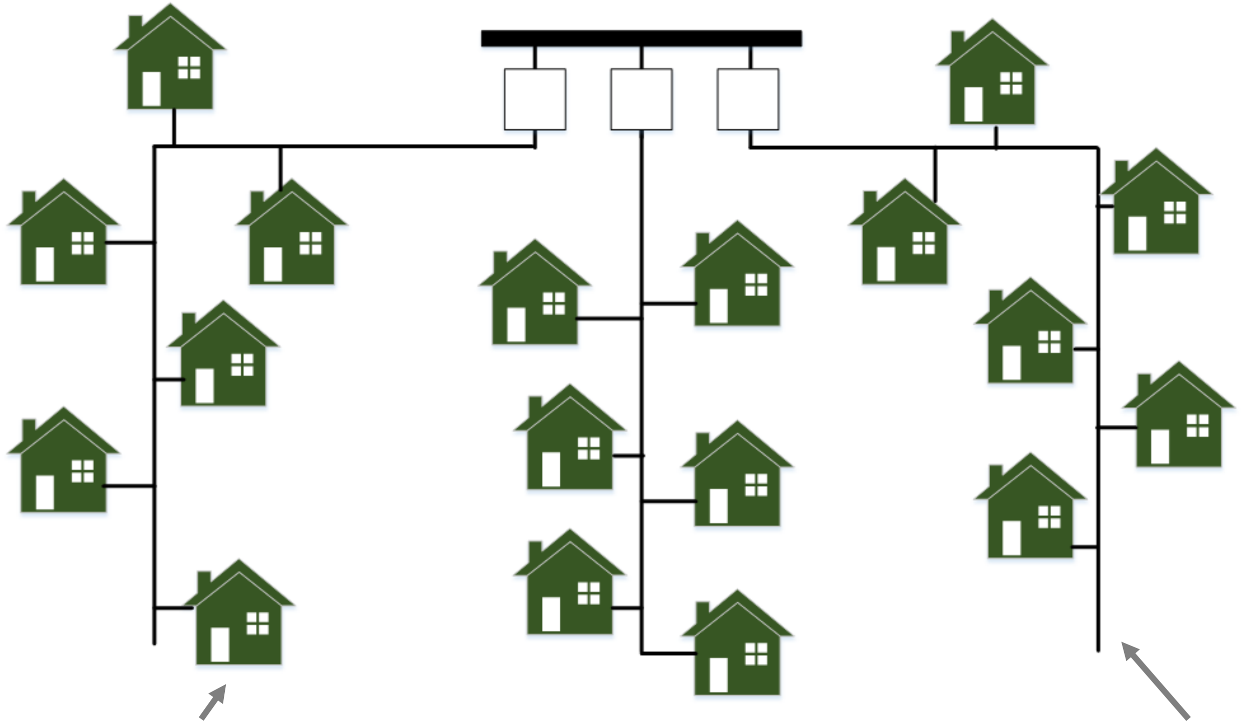
Decision Making and Optimization



Resource Optimization

- Battery Model
- Non Controlled Load

Electrical Network Constraints

- Real and Reactive Calcs
- Voltage Limits

Optimizer Output

Nodal:
- Target P/Q
- System Voltages

- Electricity Price Signal
- Maximum Power Signal
- Reference Control Signals

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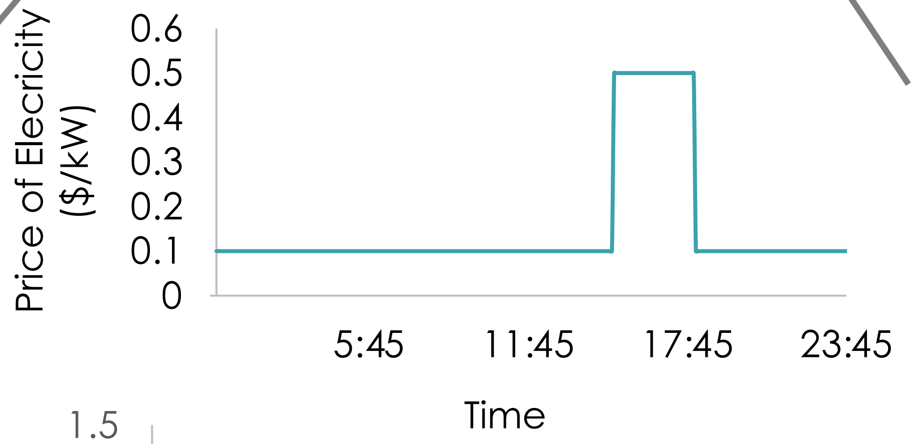
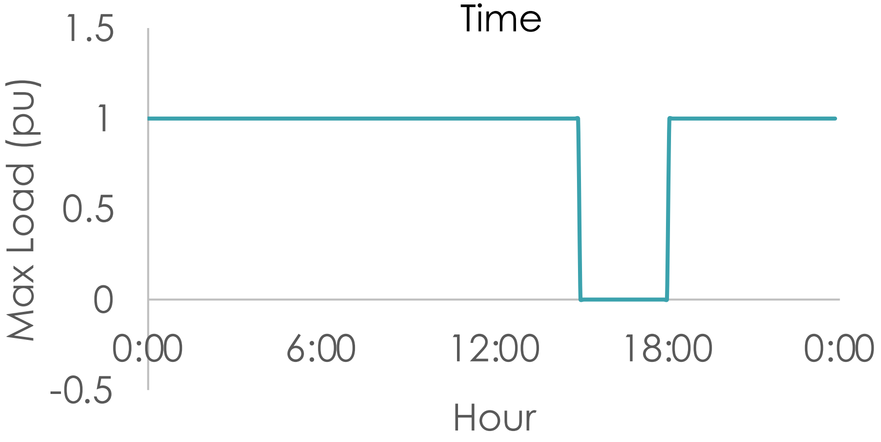
Output from Optimization and Control

TIME BASED OUTPUT REQUESTS

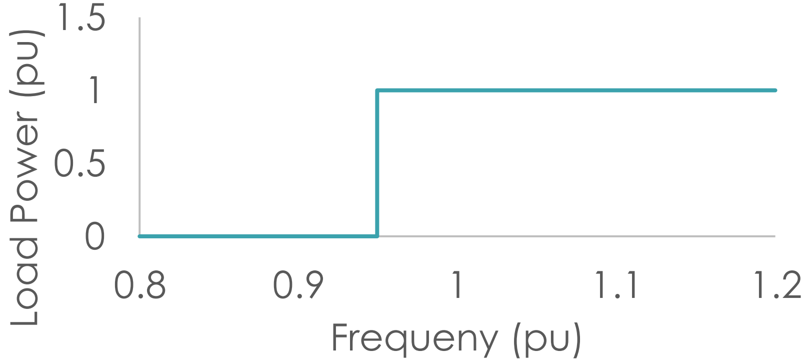
- Incentivize or restrict local control options.

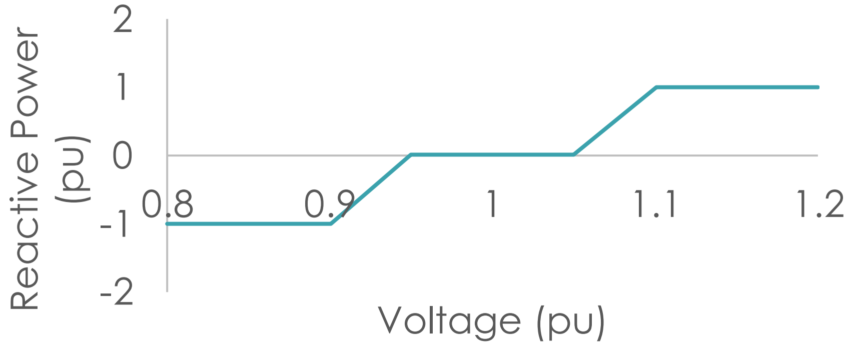


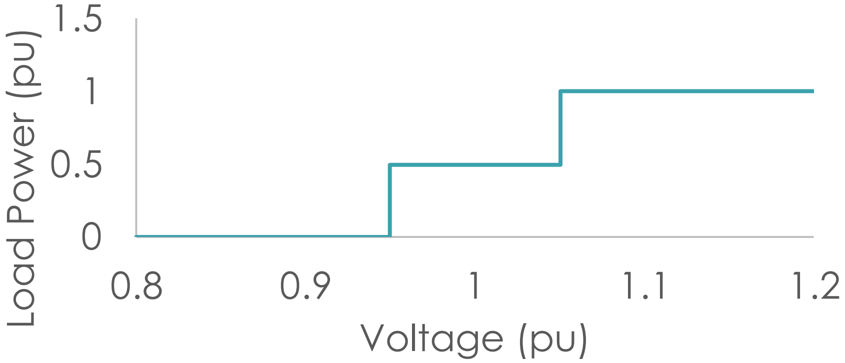


AUTONOMOUS RESPONSE

- Device performs automatic control based on local measurements -







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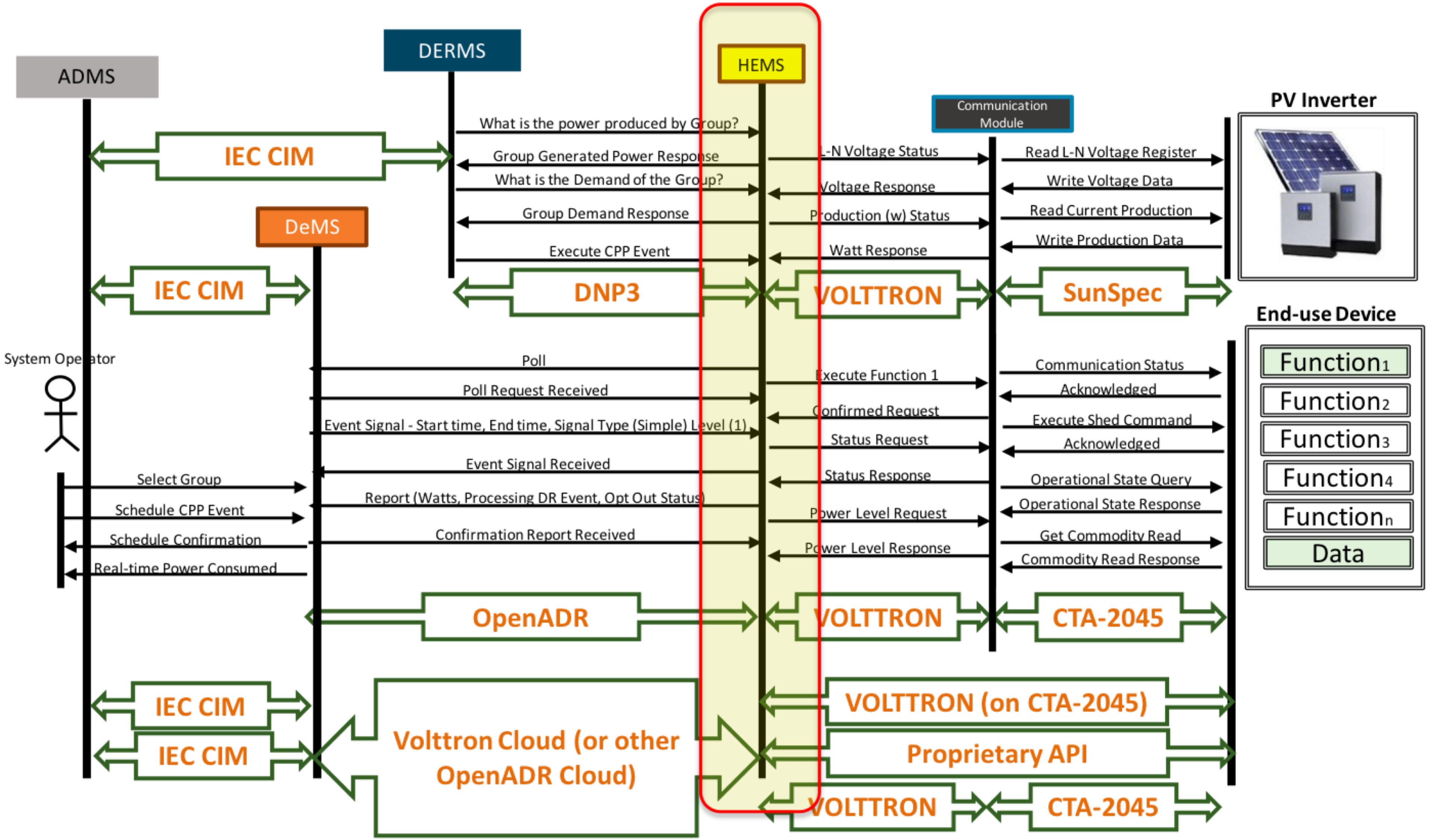
System Architecture - Detail
Enable wide-area responsive residential loads



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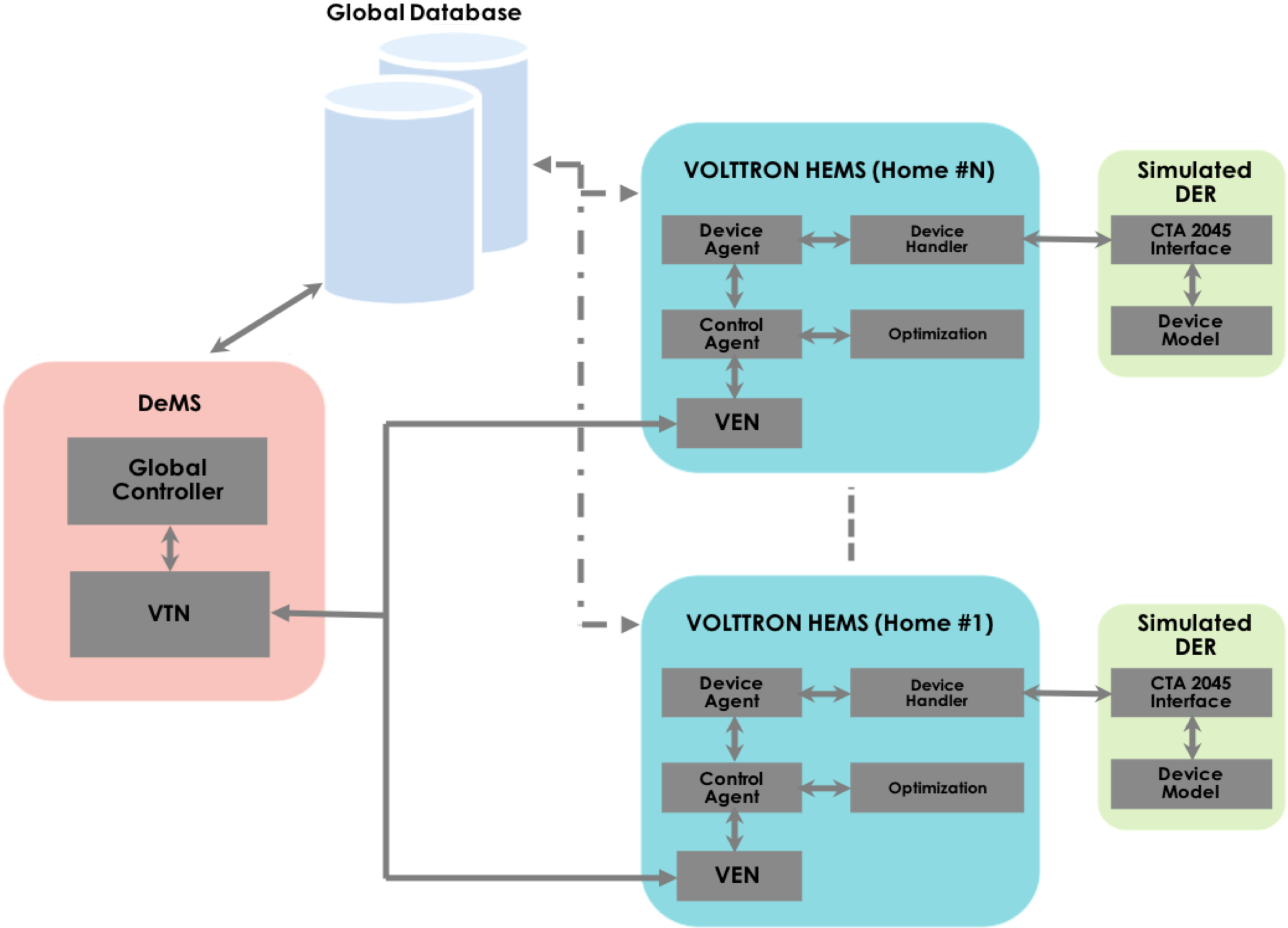
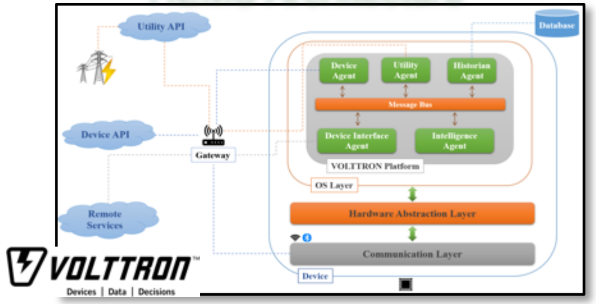
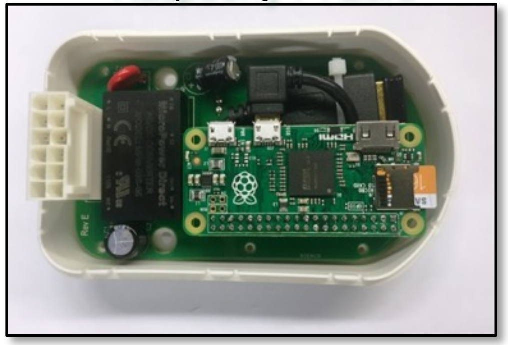
Software Architecture

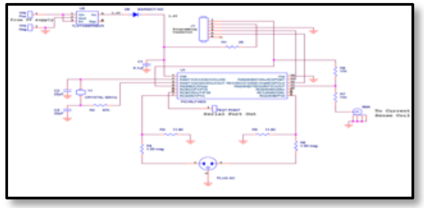


HEMS Architecture



CTA-2045 Cellular/Wi-Fi Raspberry PI Zero





Frequency and Voltage Sensing

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Project Timeline

Year 1	Year 1/Year 2	Year 3
Requirement Definition	**Technology Development**	**Field Evaluation**
Use Case Development	Edge Intelligence	Deployment & Testing
Software Specification	Transactive Control System	Evaluation Scenarios
Hardware Specification	Software Platform	
	Hardware Platform Interface to Load	

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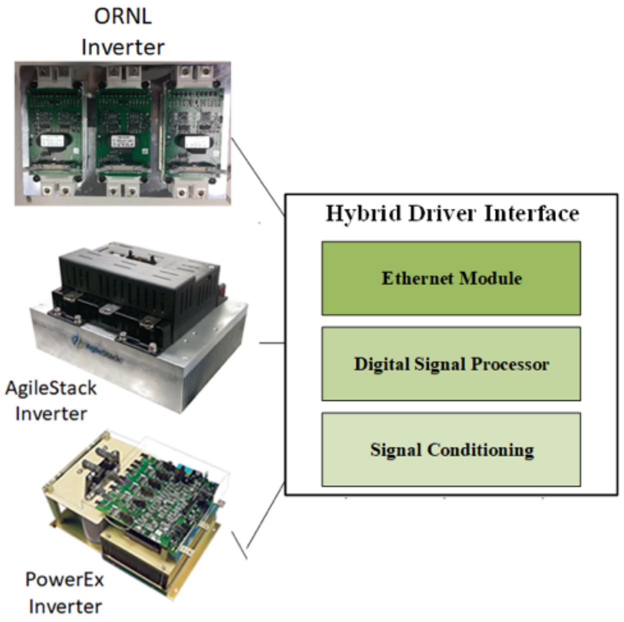
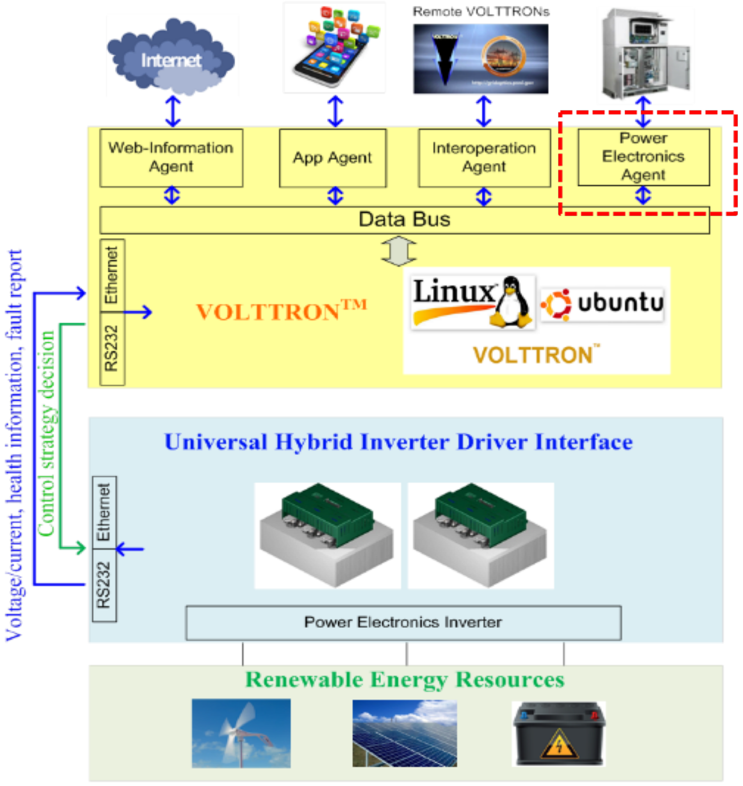
Transactive Power Electronic Systems

Objective:
Support increased efficiency for buildings and also support grid needs through advanced control and communications.

Potential Resources

- Variable Speed Loads
- Renewable Systems
- Building level energy storage





Advanced VOLTTRONTM Control Platform (Software)
- **New Power Electronics Agent Interface**
- **Control strategy decision maker**
- **Inverter status monitoring**
- **Communicate with other control platforms**

Universal Hybrid Driver Interface (Hardware)
- **Control strategy executor**
- **Universal control system coordinated with different inverter vendors**
- **Communication interface between RES and VOLTTRONTM**

Considerations:
Advanced controls should be able to be inserted into both existing and newly developed power electronic systems.

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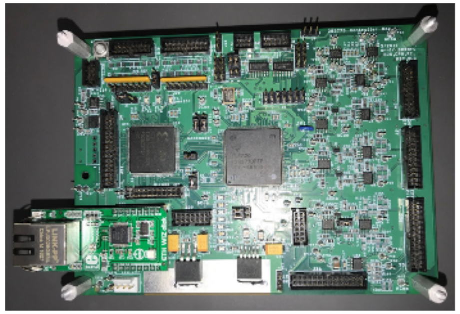
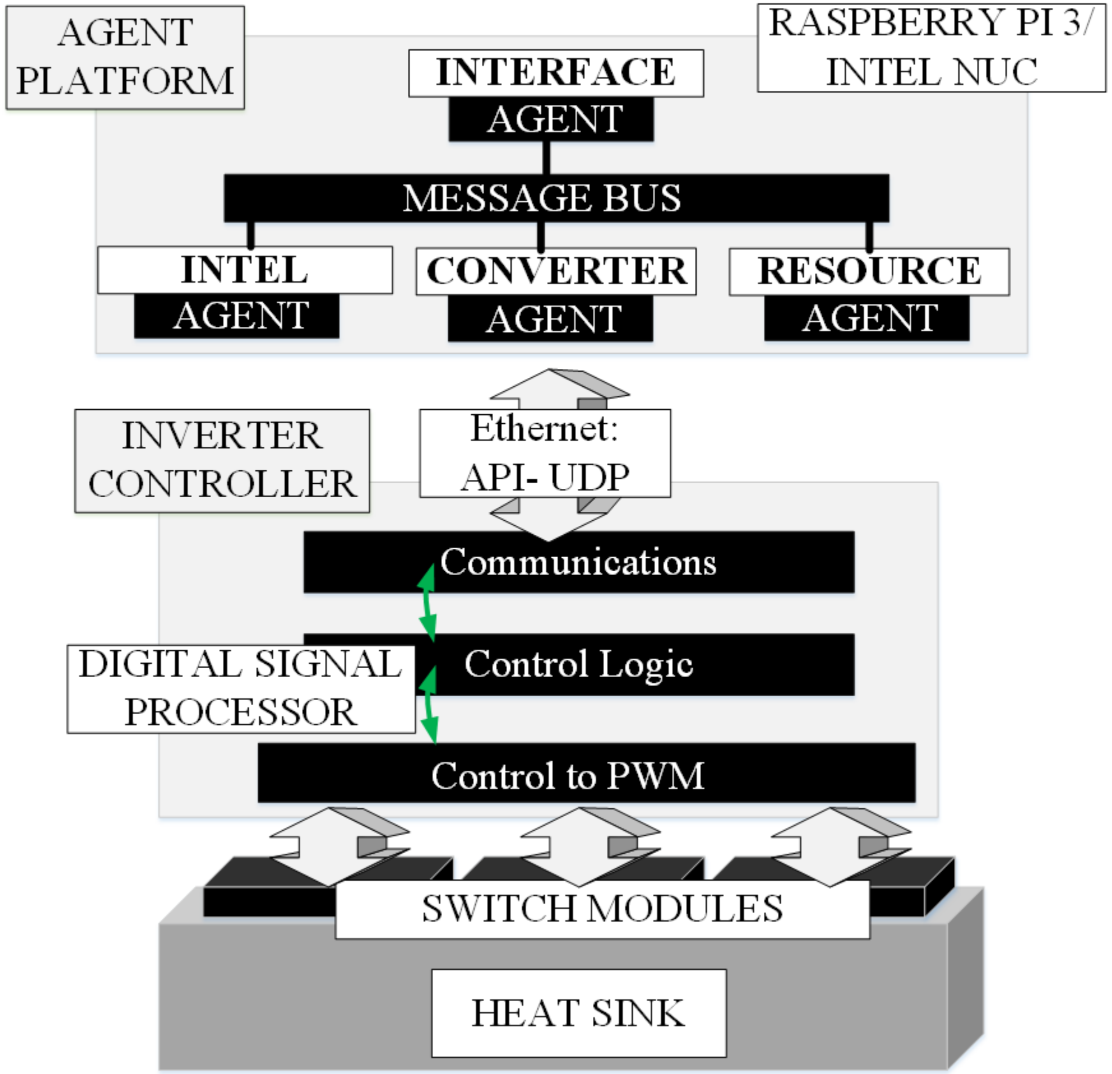
Hardware and Software Solution

Agent	Purpose
Converter	Extracts status information and sends control information to an inverter.
Resource	Extracts status information and sends control information to a resource (could be energy storage as an example)
Intelligence	Coordinates decisions between different agents to ensure full system operation.
Interface	Sends status and takes request with exterior communication systems.



ORNL-Developed Commercialized DSP Controller Employing Ethernet Port

ORNL-Developed Universal Inverter Interface



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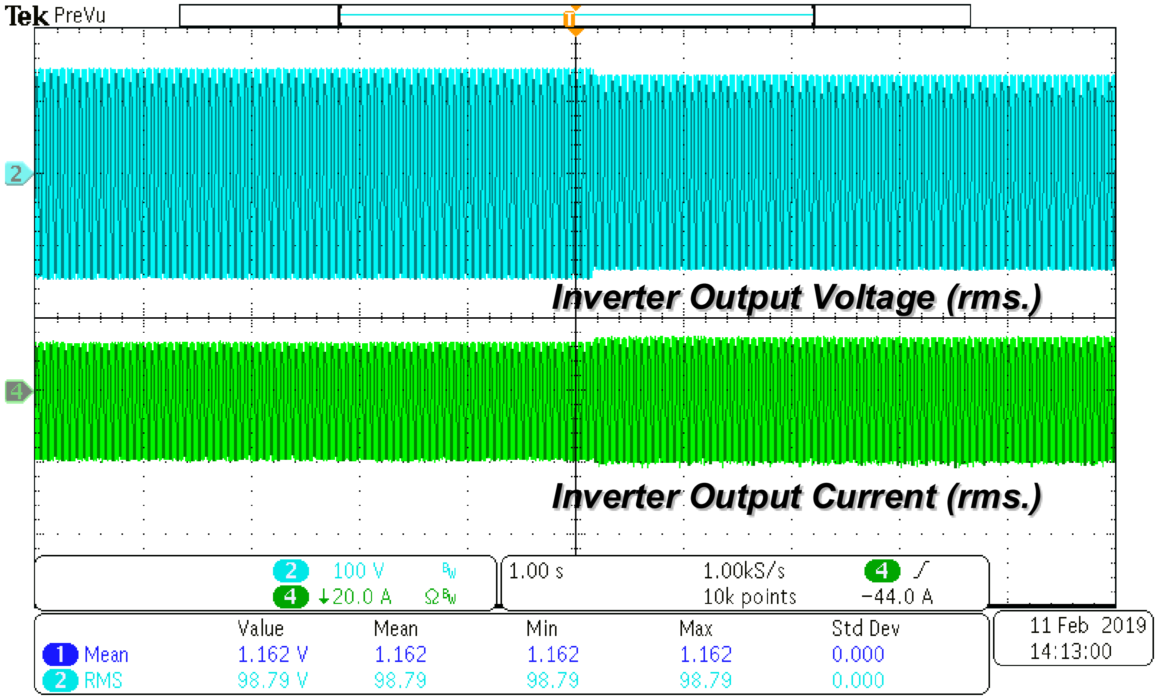
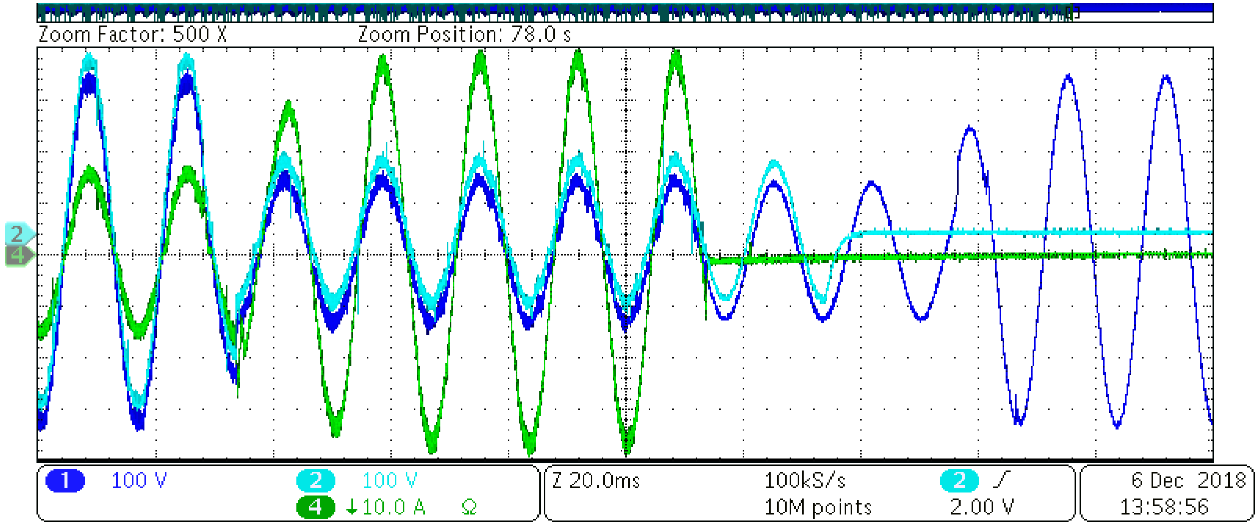
Accomplishments

Function	Role of proposed hybrid interface	Simulation verified	Coding verified
Grid-tied operation	Adaptive grid voltage tracking	✓	✓
PQ/PV/FQ mode	Power flow management	✓	✓
Islanding operation	Reconstruct a virtual grid	✓	✓
Anti-islanding protection	Seamless mode transfer through islanding detection	✓	✓
Fault ride through	Fault tolerant control	✓	✓

Automatic Mode Transition from PQ to PV
AC-120V to AC-105V, Absorb Reactive Power

PQ to PV Transition





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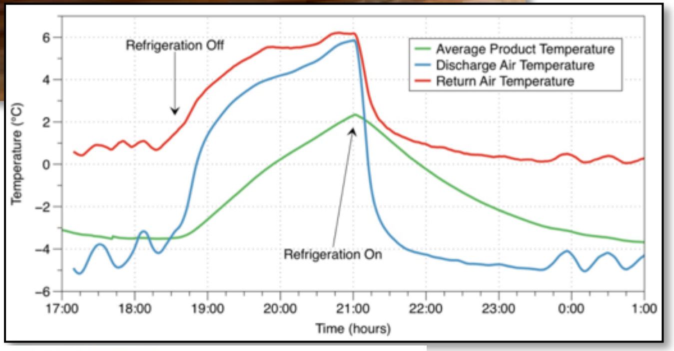
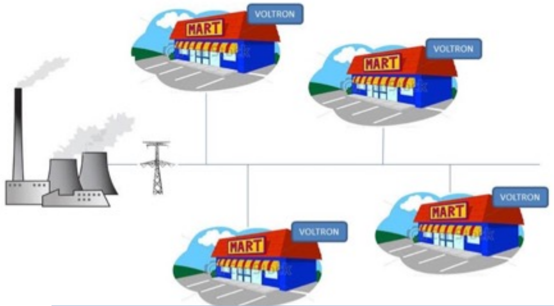
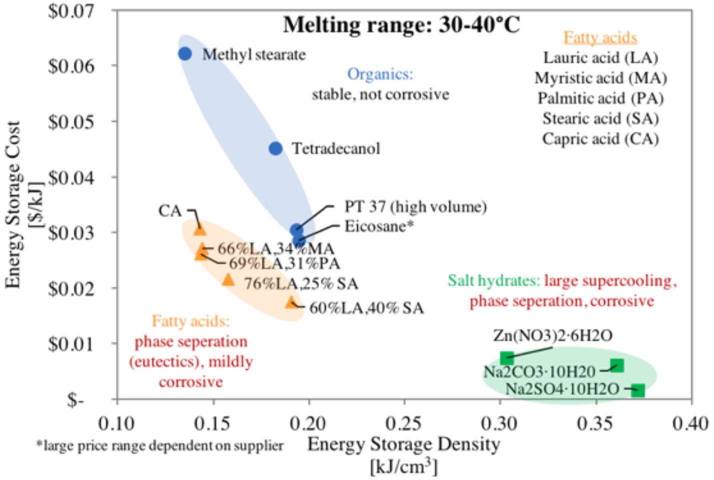
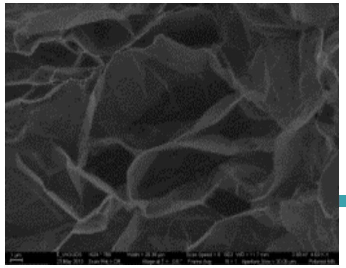
Grid Responsive Virtual and Thermal Storage

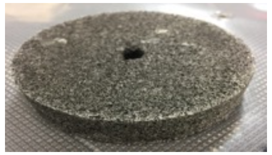




Optimal control of refrigeration sub-systems to improve grid resilience



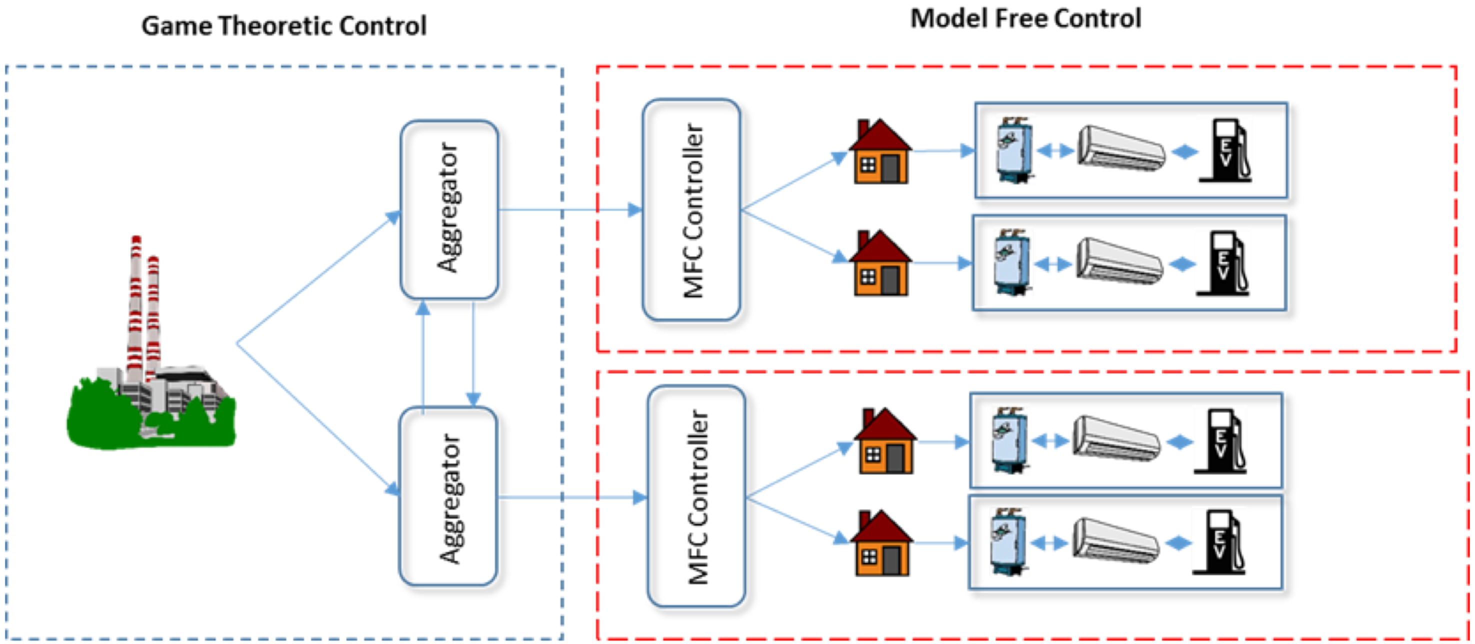




Thermal storage using highly conductive composite PCM materials

Model Free Control: Two-layer Control Scheme

- Control exists in two hierarchies
- Aggregators negotiate upstream with a utility (and in competition with each other) in a Game Theoretic control
- The aggregator controls downstream equipment with Model Free Control
- Game Theoretic control in the upper-layer is utilized to generate an optimal reference load profile for use in the MFC lower-layer



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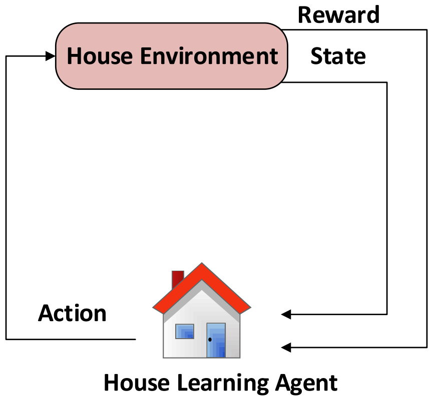
Scalable Load Management Using Reinforcement Learning

Design, develop, and field evaluate a ***transactive***, ***scalable***, and ***cost-effective*** load management system using **Reinforcement Learning (RL)**

Project Objectives

- Develop Reinforcement Learning-based optimization and control methods for understanding energy use patterns and for load scheduling
- Develop a scalable load management system to access flexibility in loads
- Perform field validation of the software framework and demonstrate benefits of running RL-based optimization and control in residential buildings



ORNL Yarnell Station Research House

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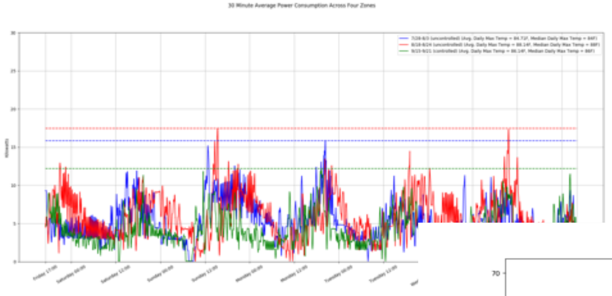
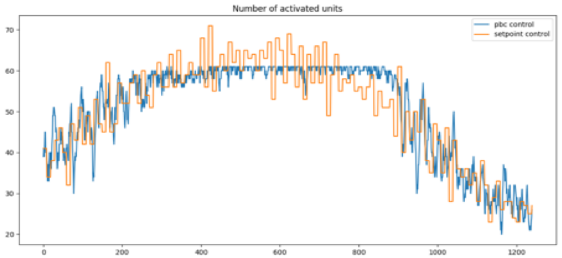
Connected Loads – Peak Demand Reduction, Grid-Responsive Loads

- Supervisory load management application
  - Flat load profile to reduce peak demand charges
  - Enable transactive applications that are revenue generating for the building owner
  - Generate desired load shape
- Deployment focused
  - **Retrofit deployment to existing stores**
  - Utilize thermal storage for demand relief
- VOLTTRON applications integrated to operational strategy
  - Embedded devices realizing control functionality
  - Scalable retrofit deployment focused

EMERSON. Climate Technologies

Southern Company

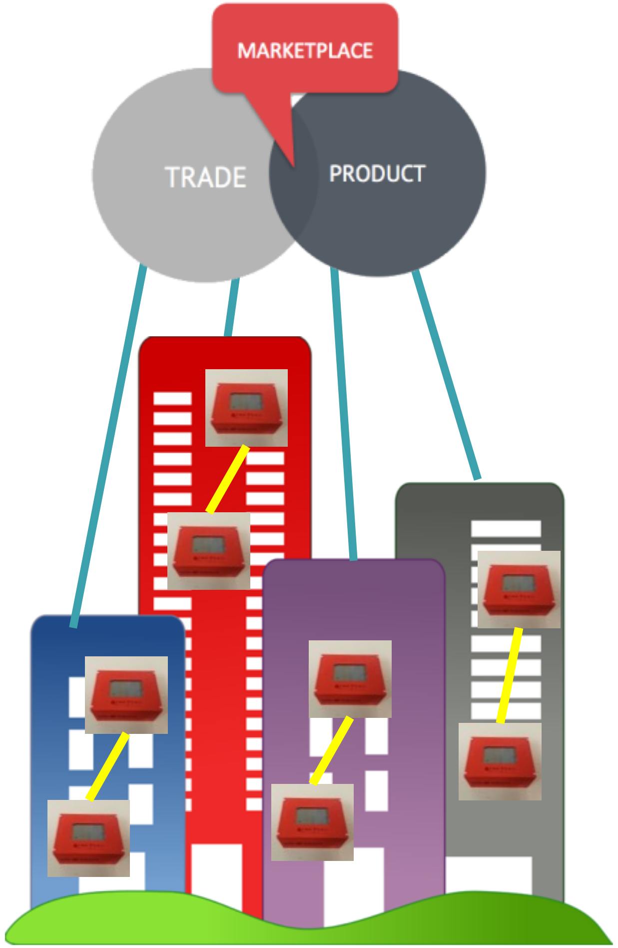




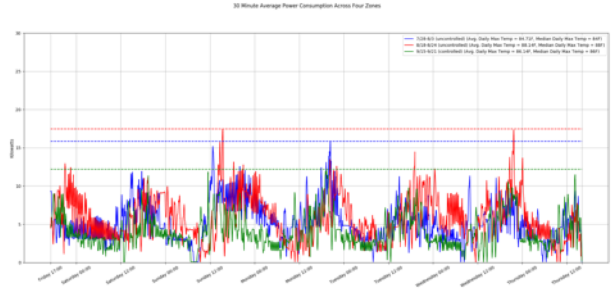
An Multi-level Strategy

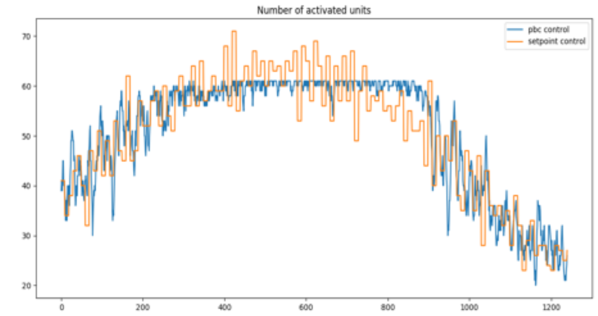
- Our goal is an integrated set of control strategies that realize the three main aims:
  - Peak demand reduction, on demand defrost
  - Energy efficiency
  - Provide services to the electrical grid
- A priority-based scheme for achieving peak demand reduction within a building
- A transactive approach to demand management
  - Priorities and nominal load are communicated to a wide-area **“marketplace”** where they serve as the “price” of supplying the service: **price a function of priority and nominal load**
  - When a demand shape is requested, the “market” clears at “price” that meets the request
  - Loads that are below the clearing price provide the service and receive the economic benefit
  - Price function constructed to favor shedding of active loads with lowest priority and highest nominal power (i.e., cheapest)

Connected loads participate in a larger marketplace to provide grid services



Connected loads within a building provide peak demand reduction and energy efficiency to the building owner





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In-Network Intelligence

- Decentralized agents with defined dynamics
- Establish communication graph of the network of nodes
- Communication channel constraints
- Develop strategy that needs to be executed – Peak Reduction etc.
- Decentralized control execution
  - slow time constant systems
  - fail-safe controls
  - low-commissioning costs

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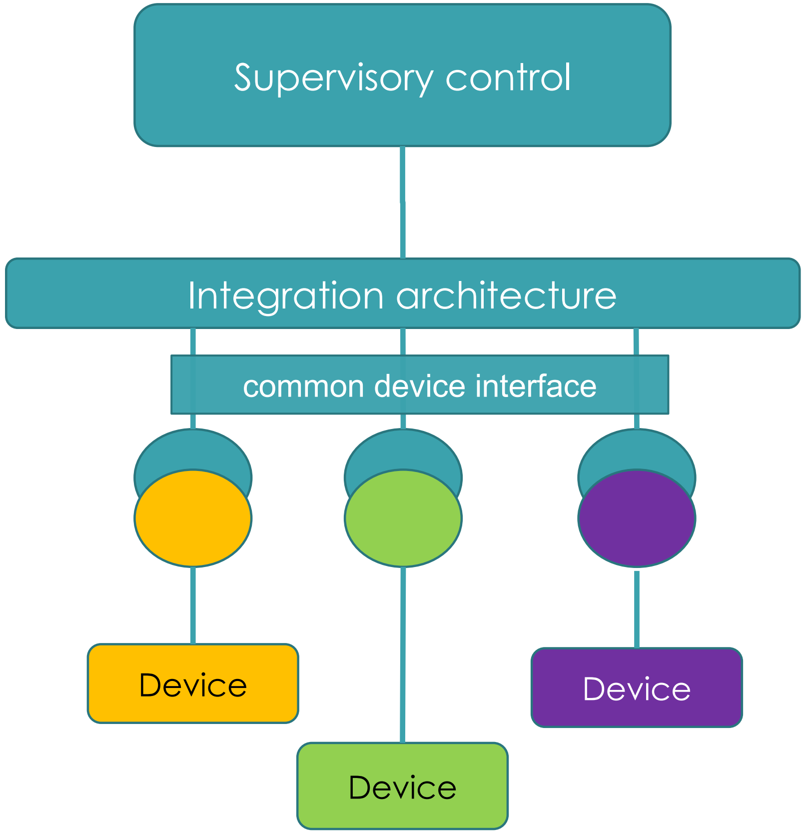
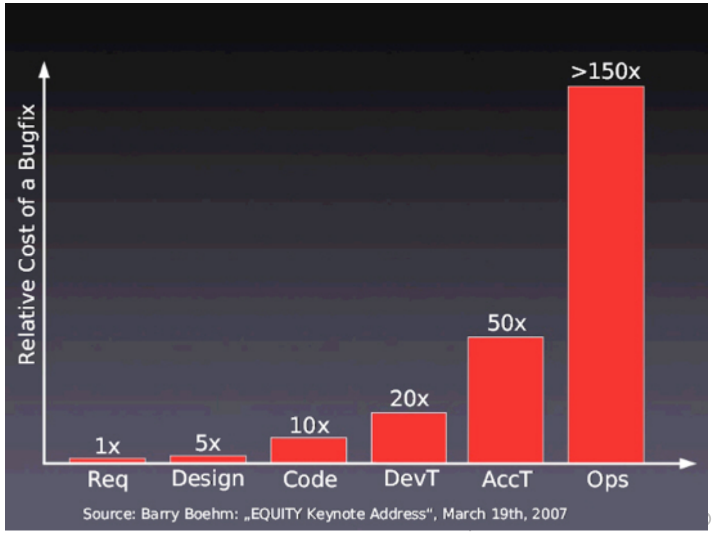
Moving forward

Automatic Commissioning

- Integrating legacy assets into these modern architectures can be costly if the legacy system comprises more than a handful of devices.
- Integration cost has two parts:
  - discovering what devices are available for use
  - building the custom software needed to glue existing devices into the integration framework.





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Moving forward

Advanced Building Equipment

- Integrate advanced sensors and controls in equipment design
  - Grid Ready appliances
  - Design Intersection: Thermal design, control design, power electronics design
- Enable advanced functionality
  - Automated Fault Detection and Diagnosis
  - Automated commissioning

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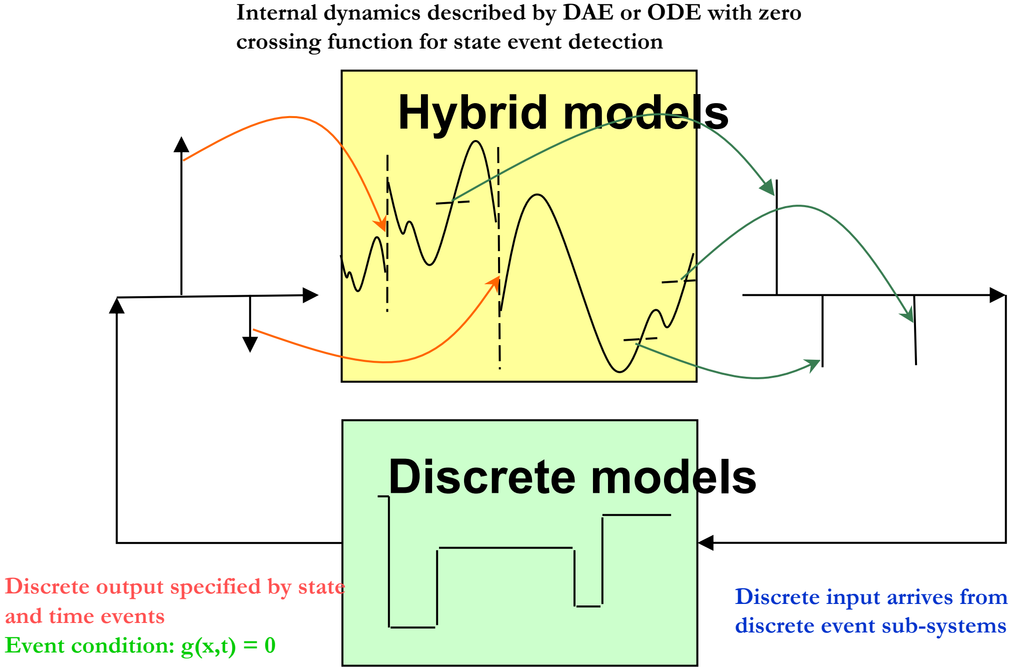
Moving Forward
Whole-building Dynamic System Modeling

- A scalable, continuous system solver.
- Integrated with a scalable algorithm for locating events that directly influence or are caused by continuous variables.
- Coupled with the management of events which indirectly influence and are influenced by the continuous variables.
- Large-scale simulation based testing



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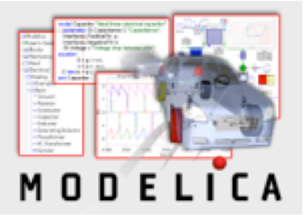
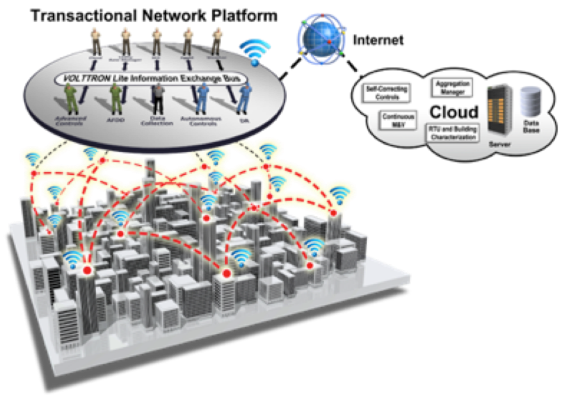
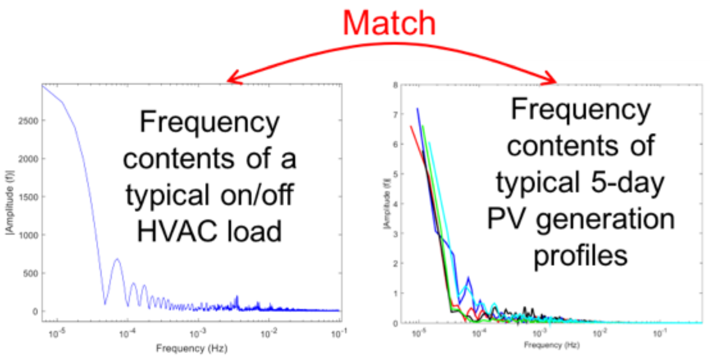
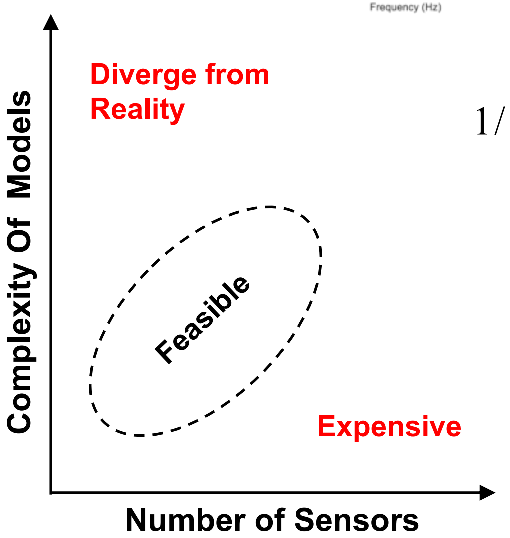


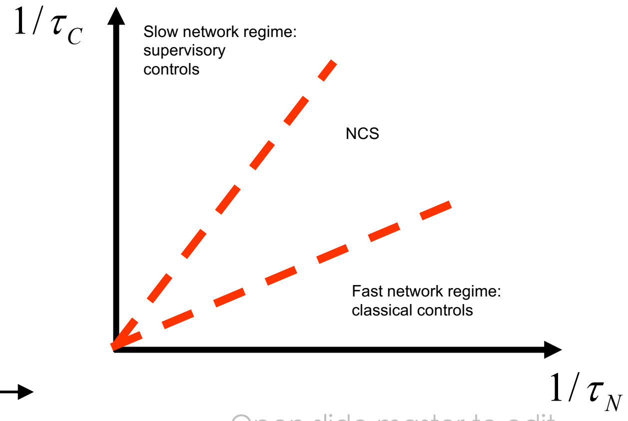
Summary

- Efficiency (building) & Resiliency (grid) can be significantly improved by responsive loads
- Transactive energy requires wide area control of loosely coupled loads
- Control response can be generated in a centralized or decentralized fashion
  - Utility level information
  - Building-level loads
- Transactive control
  - Guarantee quality of service
  - Non-ideal communication attributes
  - Stochastic energy usage and generation patterns
  - Operational constraints
  - Self-organization and aggregation









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Questions/Comments